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SOME QUANTITATIVE EXPERIMENTS IN LONG-DISTANCE RADIOTELEGRAPHY

By L. W. Austin

During December, 1909, and the spring and summer of 1910 the Navy Department carried on long-distance wireless tests between the scout cruisers *Birmingham* and *Salem* and the large Fessenden station at Brant Rock, which was leased by the Government for this purpose. These tests were primarily for the determination of the range of communication between the two cruisers and between the cruisers and the Brant Rock station. The United States Naval Wireless Laboratory had charge of the taking of certain quantitative measurements in connection with these tests, and this enabled us to obtain scientific data in regard to the laws which govern the radiation and reception of electrical waves, and, what was of especial interest, to study the course of the so-called atmospheric absorption up to a distance of about one thousand miles. The following paper contains the results of this work.

It was shown by Duddell and Taylor[1] in experiments carried on between a land station and the steamer *Monarch* in the Irish Sea that the received current over water fell off very nearly in proportion to the distance. This law has since been verified by Tissot.[2]

As the data obtained during the July experiments were by far the most full and accurate, all the theoretical deductions have been based on these results and the others have been employed only for comparison and verification. The Brant Rock station, situated directly on the shore 20 miles south of Boston, employs for its antenna a steel tower 420 feet high and 3 feet in diameter thoroughly insulated at its base. From the top of the tower extend four arms 50 feet in length and from each of these two 300-foot cylindrical cages are drawn out by means of guys at an angle of

[1] W. Duddell and J. E. Taylor, Electrician, **55**, p. 260; 1905.
[2] C. Tissot, Electrician, **56**, p. 848; 1906.

about 45°. This forms a system of eight conductors spaced symmetrically about the tower. These cages are approximately 4 feet in diameter and consist of four wires each, separated by a system of hoops. The cages are insulated at the bottom and electrically connected to the steel tower at its top, thus forming a type of umbrella antenna. The inductance of the complete antenna system amounts to 0.055 millihenry, and the capacity is 0.0073 microfarad. The closed circuit was inductively coupled to the antenna just loosely enough so that but one wave length[3] was radiated. The closed circuit condensers were of the well-known Fessenden compressed-air type, and for a wave length of 3750 meters the capacity was 0.18 microfarad. The spark gap was of the Fessenden synchronous rotary type with two fixed electrodes and a system of rotary electrodes mounted on the shaft of the generator. The generator was rated at 100 kilowatts at 500 cycles, thus producing 1000 sparks per second. It was not possible to run the generator at full power with the steam engine available at the time of the experiments, the actual power expended being 50 to 60 kilowatts.

The scout cruisers were provided with flat top antennas supported by steel masts surmounted by wooden topmasts. The antenna dimensions were: Length 116 feet, breadth 40 feet, number of longitudinal wires 14, cross wires 15. During the December test, the height above the water was approximately 112 feet, but this height was increased in the three later tests to 130 feet. The capacity was about 0.0018 microfarad and the inductance 0.038 millihenry. During the May experiments the capacity of the *Birmingham* was increased by two 70-foot cages forward and two 80-foot cages aft set at an angle of approximately 30° with the vertical. These cages were similar to those forming the umbrella of the Brant Rock tower. This increased the capacity to about 0.0025. In the midst of the July tests, cages were added to the *Salem* also, but the change resulted in no observable variation in the intensity of the signals, the increase in capacity being apparently counterbalanced by the decrease in effective height. The closed circuit was coupled to the antenna, so that but one wave length was radiated, and the closed circuit capacity was 0.036 microfarad at 3750

[3] Experience has shown that when the closed circuit is properly designed—that is, without undue waste of energy from brushing, etc.—the greatest range is obtained by a coupling loose enough to give but one wave length in the antenna.

meters, and 0.018 microfarad at 1000 meters wave length. The motor generators were 500-cycle machines rated at 10 kilowatts, and the spark gap was of the same type as that used at Brant Rock but of smaller dimensions.

JULY EXPERIMENTS

I_S. Sending antenna current in amperes.

I_R. Received antenna current through 25 ohms.

N. Night observations.

K. Received antenna current at 1 kilometer distance.

d. Distance in kilometers.

h. Height of flat top antenna.

α. Day absorption coefficient = 0.0015.

λ. Wave length.

H. Stat. Heavy static = atmospheric discharges preventing reception of signals.

Miles. Nautical mile = 1.85 kilometers.

For good communication. $I_R = 40 \times 10^{-6}$ amperes through 25 ohms $= 4 \times 10^{-8}$ watts.

For audible signals. $I_R = 10 \times 10^{-6}$ amperes through 25 ohms $= 2.5 \times 10^{-9}$ watts.

Preliminary experiments were begun early in July, the scout cruisers lying at anchor in the harbor at Provincetown, 22 miles from Brant Rock. The path of the waves between the ships and the shore station, except for a narrow strip of sand hills bounding Provincetown Harbor, lay entirely over water. Later, when the ships put to sea, it was found that this strip of land made no appreciable difference in the received signals. Careful measurements were made on the intensity of the received antenna current at Brant Rock for the two wave lengths 1 000 meters and 3 750 meters. This current was measured either by means of a hot-wire ammeter of 15 ohms resistance, provided with a mirror for mirror and scale readings,[4] or by a tellurium constantan thermo-element,[5] also of 15 ohms resistance. The hot wire ammeter gave a scale deflection of about 0.2 millimeter for 1 milliampere oscillatory current in the antenna and 9.4 millimeters for 10 milliamperes. One millimeter galvanometer deflection with the thermo-element was equivalent to 263 microamperes, and the deflections

[4] L. W. Austin, Electrical World, **49**, p. 308; 1907.

[5] This Bulletin, **7**, p. 304.

were, as nearly as could be determined, directly proportional to the square of the oscillatory current. For the 1000-meter wave length a variable air condenser was placed in series with the Brant Rock antenna, and in this way it was possible to adjust the antenna resistance for both wave lengths to about 25 ohms. From a number of observations it was determined that the received current at Brant Rock for a wave length of 1000 meters was 10 500 microamperes for the *Birmingham*, with a sending antenna current of 33 amperes,[6] and 11 000 microamperes for the *Salem*, corresponding to a sending antenna current of 27 amperes. For a wave length of 3750 meters the received currents were 3200 microamperes for the *Birmingham* and 4100 microamperes for the *Salem*, corresponding to sending antenna currents of 27 and 24 amperes.

After the ships had attained distances too great to permit the reading of the received signals at Brant Rock by means of thermo-elements, a chalcopyrite zinkite rectifier with galvanometer was employed whenever the atmospheric disturbances permitted. This was connected in a secondary circuit coupled to the antenna and calibrated by means of a thermoelement in the antenna and an exciting buzzer circuit which could be tuned to the wave length used.[7]

Throughout the experiments, both at Brant Rock and on ship-board, shunted telephone readings were taken on the incoming signals. The detectors used for the shunt readings were of the free wire electrolytic type and the head telephones connected in series were each of 600 ohms resistance,[8] the shunt being placed across one of these according to the Fessenden method. The circuits for the galvanometer and for the shunt readings at Brant Rock are shown in Fig. 1.

An extended comparison of antenna currents through circuit A and the shunt readings as taken in circuit B was made, and the

[6] It will be noticed that while the radiation current of the *Birmingham* is considerably greater than that of the *Salem*, the strength of received signal is slightly less. It is possible that the apparently greater radiation of the *Birmingham* was due to a deck insulator which gave trouble throughout the July test. It is not improbable, therefore, that the actual antenna current was not greater than that of the *Salem*. The mean of the readings of the two ships, 30 amperes at a wave length of 1000 meters, has been taken as a basis for calculation.

[7] See this Bulletin, **7**, p. 295.

[8] The inductive resistance of each telephone used in calculating the shunt ratio was 2000 ohms.

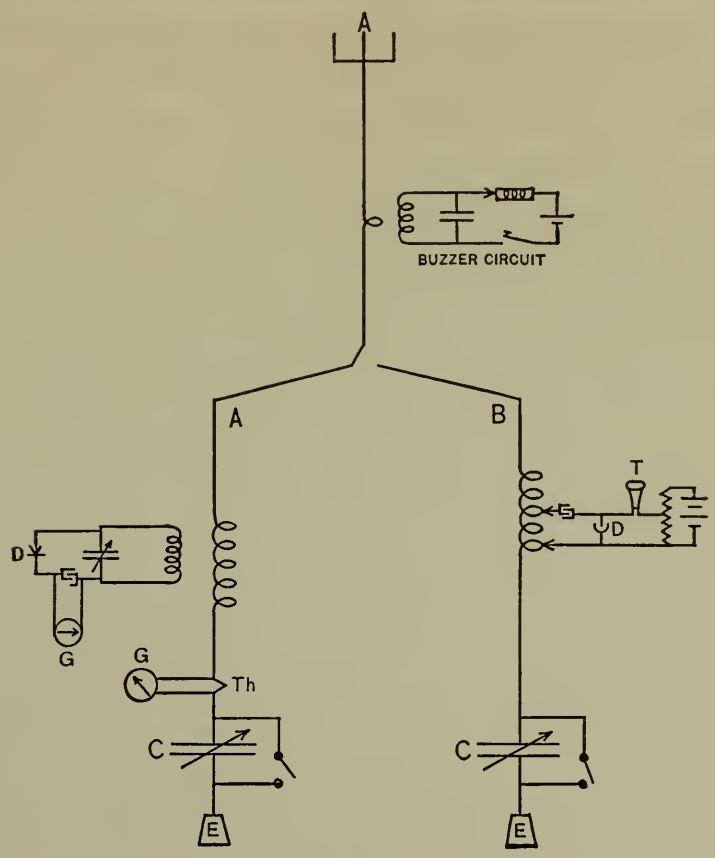

Fig. 1

TABLE I

Shunts on 600-Ohm Telephone with Electrolytic Detector, and Antenna Current Through 25 Ohms

Shunt Ohms	Antenna Current 10^{-6} Amp.	Shunt Ohms	Antenna Current 10^{-6} Amp.
0.5	672	25	95
.6	614	30	87
.7	568	40	76
.8	530	50	68
1.0	474	70	58
2	336	100	49
3	274	150	40
4	237	200	35
5	212	300	29
6	194	400	26
8	168	600	22
10	150	1000	18
12	137	2000	15
15	122	3000	13
20	106	∞	10

results are shown in Table I. The table shows the amount of current in an antenna having a total resistance of 25 ohms which would correspond to the telephone shunt readings on a detector coupled to the antenna with the degree of coupling capable of drawing the maximum amount of energy into the detector.[9]

Shunt readings are very difficult to take even under the best circumstances. In a quiet laboratory it has been found possible to make them agree among themselves with average errors in the single observations not greater than 10 per cent. In a wireless station, with its varying degree of noise, especially if the station is on shipboard, the errors are much greater than this, amounting under ordinary circumstances with good operators to from 20 to 40 per cent; while in a stormy time, or when the atmospheric discharges are heavy, the observed strength of signal will often be only a small fraction of that which would have been observed under normal conditions. It is evident that most of these sources of error tend to decrease the observed value of the signal. Occasionally, however, a loose contact or a loose plug where plug resistance boxes are used, will produce abnormally high values. Then, too, the difference in ear sensitiveness of different operators produces variations in the record. For this reason it is necessary that a very large number of observations be taken to make the results of much value.

As the received currents given in the curves and tables are proportional to the square root of the loudness of signal, the percentage errors are of course smaller than the errors in taking the shunt readings.

The standard of audibility taken in this work is that strength of signal which permits a clear differentiation of the dots and dashes.

The *Birmingham* sailed from Provincetown early on the morning of July 14, taking a course nearly south until she had attained a distance of about 1200 miles from Brant Rock. The *Salem*

[9] The actual amount of current in the antenna for the same intensity of signal in the detector varies with the effective resistance, which in turn depends on the wave length and amount of tuning inductance. The energy in the detector, required to produce given signals is constant, however. This energy is what is actually measured in taking shunt readings, and for convenience of comparison its square root is put in terms of micro amperes through 25 ohms which was the resistance actually employed in the thermoelement readings at Brant Rock, and which is approximately the effective resistance of a properly coupled ship's antenna of moderate size at a wave length of 1000 meters.

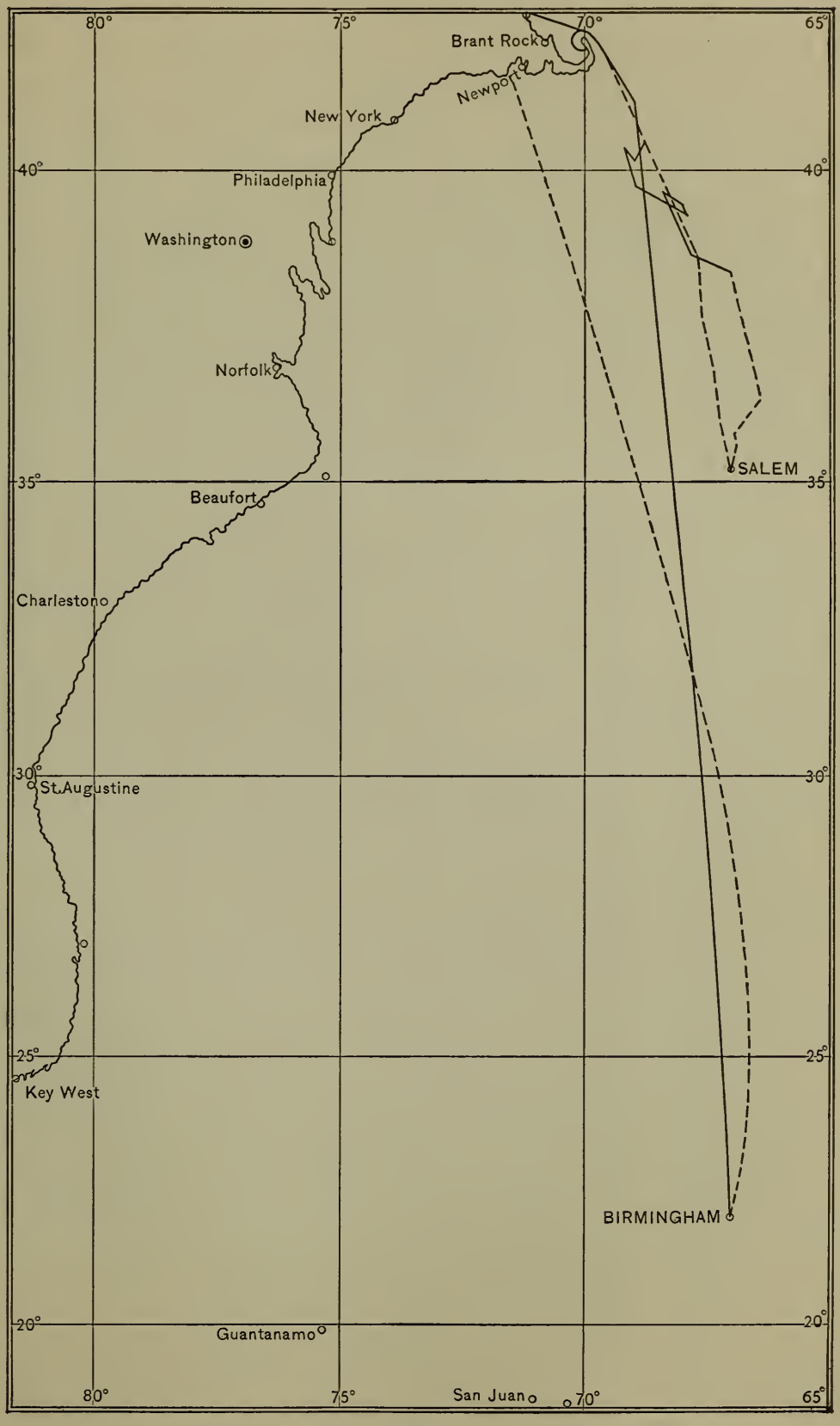
80°
75°
70°
65°
Brant Rock
Newport
New York
40°
Philadelphia
Washington
Norfolk
SALEM
35°
Beaufort
Charleston
30°
St. Augustine
25°
Key West
BIRMINGHAM
20°
Guantanamo
San Juan

Fig. 2

TABLE II

Birmingham Received at Brant Rock

July		λ=1000 M. I_s=33 amp. Distance, Nautical Miles	Received Current 10^{-6} amp.		July		λ=3750 M. I_s=27 amp. Distance, Nautical Miles	Received Current 10^{-6} amp.	
14	8 a. m.	22		10500 (Galvanometer)	14	8.30 a. m.	22		3000 (Galvanometer)
	2 p. m.	50		4600 (Galvanometer)		3.30 p. m.	60		1370 (Galvanometer)
	8 p. m.	110	N	2100 (Galvanometer)		9.30 p. m.	120	N	520 (Galvanometer)
15	8 a. m.	256		520 (Galvanometer)	15	9.30 a. m.	266		180 (Galvanometer)
	2 p. m.	335		157 (Galvanometer)		3.30 p. m.	345		67
	8 p. m.	415	N	336		9.30 p. m.	425	N	77
16	8 a. m.	550		77	16	9.30 a. m.	560		49
	2 p. m.	626		54		3.30 p. m.	636		H. Stat.
	8 p. m.	702	N	210		9.30 p. m.	712	N	106
17	8 a. m.	854		H. Stat.	17	9.30 a. m.	864		26
	2 p. m.	927				3.30 p. m.	937		Stat.
	8 p. m.	1000	N	19		9.30 p. m.	1010	N	10
18	8 a. m.	1170		H. Stat.	18	9.30 a. m.	1170		
	2 p. m.	1185		H. Stat.		3.30 p. m.	1185		
	8 p. m.	1200	N	51		9.30 p. m.	1200	N	44
19	8 a. m.	1152		H. Stat.	19	9.30 a. m.	1152		26
	2 p. m.	1103		H. Stat.		3.30 p. m.	1103		
	8 p. m.	1035	N	210		9.30	1025	N	Not send
20	8 a. m.	890		35	20	9.30 a. m.	880		26
	2 p. m.	841		29		3.30 p. m.	831		
	8 p. m.	772	N	240		9.30 p. m.	762	N	Not send
21	8 a. m.	648		26	21	9.30 a. m.	638		26
	2 p. m.	559				3.30 p. m.	549		
	8 p. m.	470	N	150		9.30	460	N	Not send
22	8 a. m.	320		210	22	9.30 a. m.			
	2 p. m.	240				3.30 p. m.			
	8 p. m.	190				9.30 p. m.			

followed on the morning of July 15 and proceeded slowly to a point about 450 miles from Brant Rock. The courses of the two ships are shown in figure 2. Regular sending and receiving periods were observed at the three stations. At Brant Rock the signals were received as far as possible on the thermoelement and a few readings were taken with the rectifier, but while the preceding week had been almost completely free from atmospheric disturbances, unfortunately, soon after the ships sailed, strong disturbances set in which precluded the possibility of galvanometer measurements, so that for the rest of the experiments all the readings had to be taken by the shunted telephone method. On the ships no attempt was made to use deflection methods, although

TABLE III

Brant Rock Received on Birmingham

July		λ=1500 m I_s=56 amp.			July		λ=3750 m I_s=69 amp.		
		Distance, Nautical Miles		Received Current 10^{-6} amp.			Distance, Nautical Miles		Received Current 10^{-6} amp.
15	10.15 a. m.	290		336	15	10.45 a. m.	295		120
	10.15 p. m.	445	N	274		10.45 p. m.	450	N	63
16	10.15 a. m.	580		58	16	10.45 a. m.	585		
	10.15 p. m.	727	N	160		10.45 p. m.	732	N	77
17	10.15 a. m.	885		28	17	10.45 a. m.	890		
	10.15 p. m.	1040	N	106		10.45 p. m.	1045	N	37
18	10.15 a. m.	1180		Stat.	18	10.45 a. m.	1185		
	10.15 p. m.	1215	N	130		10.45 p. m.	1215	N	110
19	10.15 a. m.	1115		Stat.	19	10.45 a. m.	1110		30
	10.15 p. m.	1005	N	106		10.45 p. m.	1000	N	212
20	10.15 a. m.	850		37	20	10.45 a. m.	845		28
	10.15 p. m.	730	N	336		10.45 p. m.	725		Not send
21	10.15 a. m.	600		150	21	10.45 a. m.	595		51
	10.15 p. m.	435	N	194		10.45 p. m.	430	N	54
22	10.15 a. m.	275		390	22	10.45 a. m.	270		Not send
	10.15 p. m.	115	N	336		10.45 p. m.	110		Not send

it is possible that satisfactory measurements could have been taken by means of marine galvanometers. Tables II to VI contain the data of the experiments, the received signals being reduced to terms of current through 25 ohms antenna resistance.

TABLE IV

Salem Received at Brant Rock

July		λ=1000 m I_s=27 amp. Distance, Nautical Miles		λ=1000 m I_s=27 amp. Received Current 10^{-6} amp.	July		λ=3750 m I_s=23 amp. Distance, Nautical Miles		λ=3750 m I_s=23 amp. Received Current 10^{-6} amp.
					15	6 a. m.	22		4400
15	5 a. m.	22		11000		9 a. m.	52		1420
	8 a. m.	45		5000		3 p. m.	70		1250
	2 p. m.	60		3600		9 p. m.	117	N	* 613
	8 p. m.	117	N	2170					
16	8 a. m.	125		2250	16	9 a. m.	130		693
	2 p. m.	105		2275		3 p. m.	110		* 567
	8 p. m.	137	N	1328		9 p. m.	140	N	* 474
17	8 a. m.	207		* 1062	17	9 a. m.	210		* 274
	2 p. m.	190		646		3 p. m.	190		* 500
	8 p. m.	196	N	400		9 p. m.	196	N	* 179
18	8 a. m.	249		580	18	9 a. m.	250		* 237
	2 p. m.	270		520		3 p. m.	275		* 274
	8 p. m.	290	N	410		9 p. m.	295	N	* 194
19	8 a. m.	366		200	19	9 a. m.	370		* 106
	2 p. m.	394		182		3 p. m.	400		* 115
	8 p. m.	425	N	* 672		9 p. m.	430		Not send
20	8 a. m.	322		325	20	9 a. m.	315		Not send
	2 p. m.	254		582		3 p. m.	245		Not send
	8 p. m	181	N	Stat.		9 p. m.	175		Not send

* Telephone readings

Wherever possible the readings taken by the deflection method are used. During the experiments the atmospheric disturbances were heavy most of the time, especially at night and at the longer wave length. These frequently entirely prevented the reception of the signals as indicated by the blanks in the received current column. No table is given for Brant Rock received on the *Salem*,

because during a great part of the time the signals were too strong for accurate shunt readings. No tables are given for the work between the two cruisers at a wave length of 3 750 meters, as their antennas seemed too small to work successfully at this

TABLE V

"Salem" Received on "Birmingham"

July		$\lambda = 1000$ m $I_s = 27$ Amp.	
		Distance, Nautical Miles	Received Current 10^{-6} Amp.
15	8 a. m.	253	170
	2 p. m.	274	196
	8 p. m.	312	N 120
16	8 a. m.	420	87
	2 p. m.	521	54
	8 p. m.	574	N 87
17	8 a. m.	661	21
	2 p. m.	750	20
	8 p. m.	840	N 30
18	8 a. m.	960	Stat.
	2 p. m.	972	Stat.
	8 p. m.	960	N 46
19	8 a. m.	828	10
	2 p. m.	720	26
	8 p. m.	618	N 46
20	8 a. m.	589	43
	2 p. m.	566	54
	8 p. m.	555	N 69
21	8 a. m.	666	46
	2 p. m.		
	8 a. m.		

TABLE VI

"Birmingham" Received on "Salem"

July		$\lambda = 1000$ m $I_s = 33$	
		Distance, Nautical Mile	Received Current 10^{-6} Amp.
15	8.30 a. m.	256	160
	2.30 p. m.	278	150
	8.30 p. m.	315	N 105
16	8.30 a. m.	425	60
	2.30 p. m.	526	43
	8.30 p. m.	579	N 63
17	8.30 a. m.	666	H. Stat.
	2.30 p. m.	755	H. Stat.
	8.30 p. m.	845	N 38
18	8.30 a. m.	960	10
	2.30 p. m.	972	10
	8.30 p. m.	960	N 10
19	8.30 a. m.	823	10
	2.30 p. m.	715	Stat.
	8.30 p. m.	613	N 77
20	8.30 a. m.	584	38
	2.30 p. m.	561	38
	8.30 p. m.	555	Messages
21	8 30 a. m.	661	38

wave length and only a few unsatisfactory shunt readings were obtained.

For determining the law of the decrease of the intensity of the signal with the distance a smooth curve was drawn through the observed day readings and points on this were taken as the

TABLE VII

Birmingham Received at Brant Rock, July

Nautical Miles	d Km	I_S=33 amp. λ=1000 m. K=475000 10^{-6} amp.			I_S=27 amp. λ=3750 m. K=138000 10^{-6} amp.		
		$\frac{K}{d}$ 10^{-6} amp.	I_R 10^{-6} amp.		$\frac{K}{d}$ 10^{-6} amp.	I_R 10^{-6} amp.	
			Obs.	Cal.		Obs.	Cal.
20	37	12830	11500	12200	3730	3500	3620
50	92.5	5135	4600	4460	1492	1400	1385
100	185	2565	2100	1940	746	700	645
200	370	1283	800	737	373	260	280
300	555	856	260	370	249	120	161
400	740	642	130	212	187	60	105
500	925	514	80	128	149	40	73
600	1110	428	50	81.5	124	30	52
800	1480	321	35	35	93	24	29
1000	1850	257	20	15.4	75	22	18

TABLE VIII

Brant Rock Received on Birmingham, July

Nautical Miles	d Km	I_S=56 amp. λ=1500 m K=310000.10^{-6} amp.			I_S=69 amp. λ=3750 m K=160000.10^{-6} amp.		
		$\frac{K}{d}$ 10^{-6} amp.	I_R 10^{-6} amp.		$\frac{K}{d}$ 10^{-6} amp.	I_R 10^{-6} amp.	
			Obs.	Cal.		Obs.	Cal.
20	37	8380		8000	4325		4200
50	92.5	3350		2980	1730		1610
100	185	1675		1340	865		750
200	370	838		533	432		324
300	555	558	320	283	288	120	187
400	740	419	160	170	216	85	121
500	925	335	80	108	173	65	84.5
600	1110	279	52	72.5	144	52	60.8
800	1480	209	38	34.7	108	40	34.1
1000	1850	167	25	17.1	87	30	20.6

observed values for purposes of calculation. It was assumed from the results of Duddell and Taylor and Tissot that the received currents would be inversely proportional to the distance provided no absorption existed. The observed curve indicated that this was approximately true up to a point between 100 and 200 miles, but beyond this point the currents evidently dropped much more rapidly. The simplest assumption in regard to absorption is that it is proportional to the distance. Joining this to the Duddell and Taylor law we have as an expression for the received current

$$I_R = \frac{K}{d} e^{-Ad} \qquad (1)$$

where d is the distance, K the received current at unit distance, e the base of the natural logarithms, and A a constant. Dr. Louis Cohen of the National Electric Signaling Co., while testing the validity of this formula made the discovery that A was inversely proportional to the square root of the wave length within the limits of accuracy of the observations. Then, writing $A = \frac{\alpha}{\sqrt{\lambda}}$ the expression becomes

$$I_R = \frac{K}{d} e^{-\frac{\alpha d}{\sqrt{\lambda}}} \qquad (2)$$

α is the absorption coefficient and in these experiments equals 0.0015, the distance and wave length being expressed in kilometers.

Tables VII to XI contain a comparison of the calculated values with those taken from the smoothed observation curves. It is seen that the agreement is exceedingly good in the case of the signals between the *Birmingham* and the *Salem* and those of the *Salem* received at Brant Rock. In the case of the signals between Brant Rock and the *Birmingham*, however, the observed values fall somewhat below the calculated, from 300 to 600 miles. As the observed curve has the same form both for the signals received on the *Birmingham* and those received at Brant Rock the divergence is probably not accidental, and is probably due to a temporary increase of absorption accompanying a marked change in the weather at about this time. The effect is not observed in the *Salem* signals received at Brant Rock because the *Salem* at this time had not attained a great enough distance to make the absorption play an important part.

TABLE IX

"Salem" Received at Brant Rock, July

Nautical Miles	d Km	I_S=27 Amp. λ=1000 m K=490000 10^{-6} Amp.			I_S=23 Amp. λ=3750 m K=170000 .10^{-6} Amp.		
		$\frac{K}{d}$ 10^{-6} Amp.	I_R 10^{-6} Amp.		$\frac{K}{d}$ 10^{-6} Amp.	I_R 10^{-6} Amp.	
			Obs.	Cal.		Obs.	Cal.
20	37	13250	12000	12500	4595	4500	4460
50	92.5	5300	4700	4610	1838	1800	1710
100	185	2650	2200	2000	919	850	800
150	278	1760	1200	1170	612	500	495
200	370	1325	750	760	459	330	344
300	555	883	370	382	306	190	198
400	740	662	200	218	230	115	129
500	925	530	130	132	184	88	90

TABLE X

Salem Received on Birmingham, July

Nautical Miles	d Km	I_s=27 amp. λ=1000 m. K=230000 10^{-6} amp.		
		$\frac{K}{d}$ 10^{-6} amp.	I_R 10^{-6} amp.	
			Obs.	Cal.
20	37	6220		5880
50	92.5	2486		2160
100	185	1243		941
200	370	622	325	357
300	555	414	165	179
400	740	311	95	102
500	925	249	65	62
600	1110	207	45	39.4
800	1480	155	19	17.1
1000	1850	124	10	7.5

TABLE XI

Birmingham Received on Salem, July

Nautical Miles	d Km	I_s=33 amp. λ=1000 m. K=185000 10^{-6} amp.		
		$\frac{K}{d}$ 10^{-6} amp.	I_R 10^{-6} amp.	
			Obs.	Cal.
20	37	5000		4730
50	92.5	2000		1740
100	185	1000		757
200	370	500	260	287
300	555	333	130	144
400	740	250	75	82.4
500	925	200	50	49.9
600	1110	167	35	31.7
800	1480	125	16	13.8
1000	1850	100	10	6.2

The curves of figures 3 to 10 give the results in graphic form. The dotted line gives the strength of signal which would have been received if the K/d law had obtained; that is, if there had been no absorption. The continuous curve gives the theoretical day values as calculated from equation 2, while the individual observations

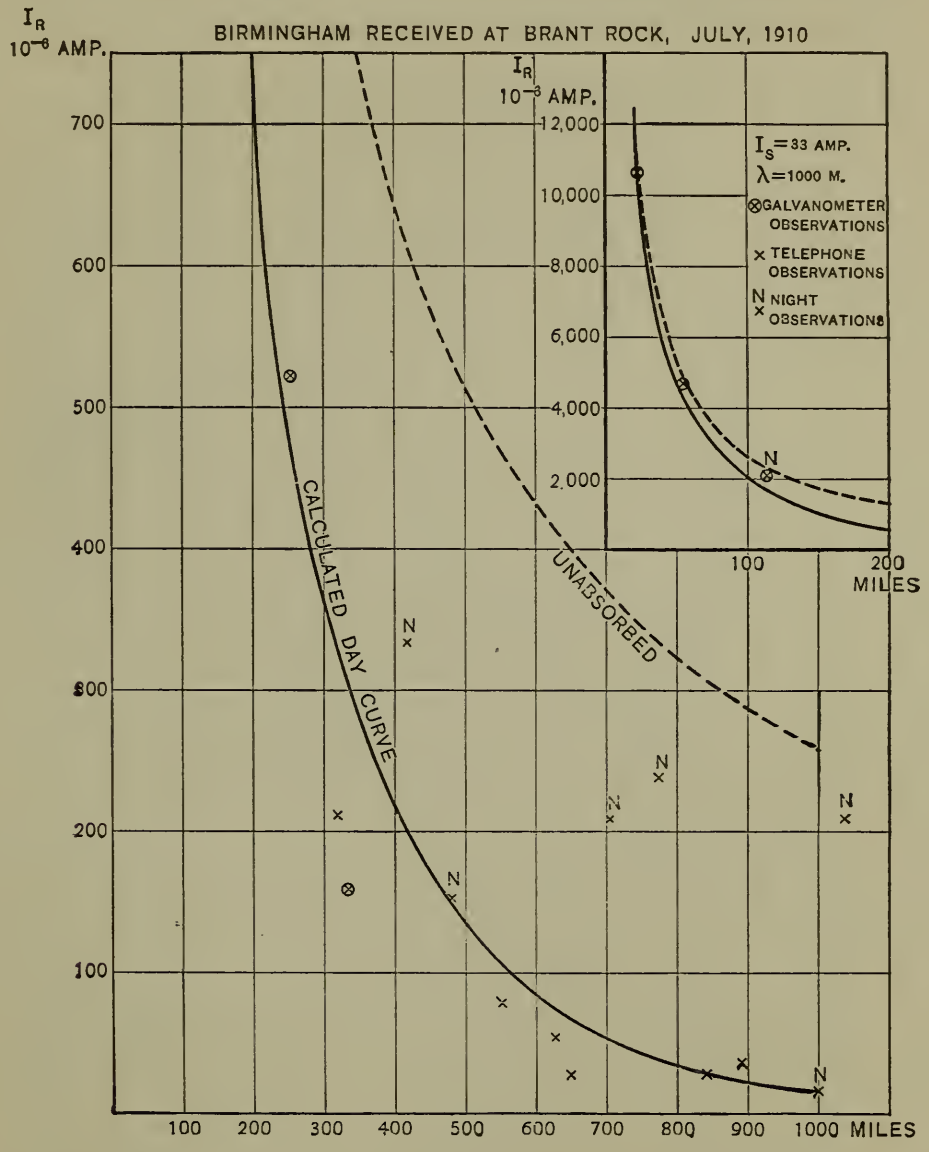

Fig. 3

are represented by crosses. Observations taken by the deflection method are indicated by circles around the crosses, while night observations are accompanied by the letter N. It is seen that the day observations correspond approximately to the values of the calculated curve, but that the night signals are entirely irregular,

being in general stronger than the day signals, as was first observed by Marconi. Sometimes they lie close to the K/d curve, indicating that the absorption has disappeared, while at others they are practically of the same strength as the day readings. In a very few cases, night signals were observed considerably stronger than the calculated value for zero absorption, but these may very

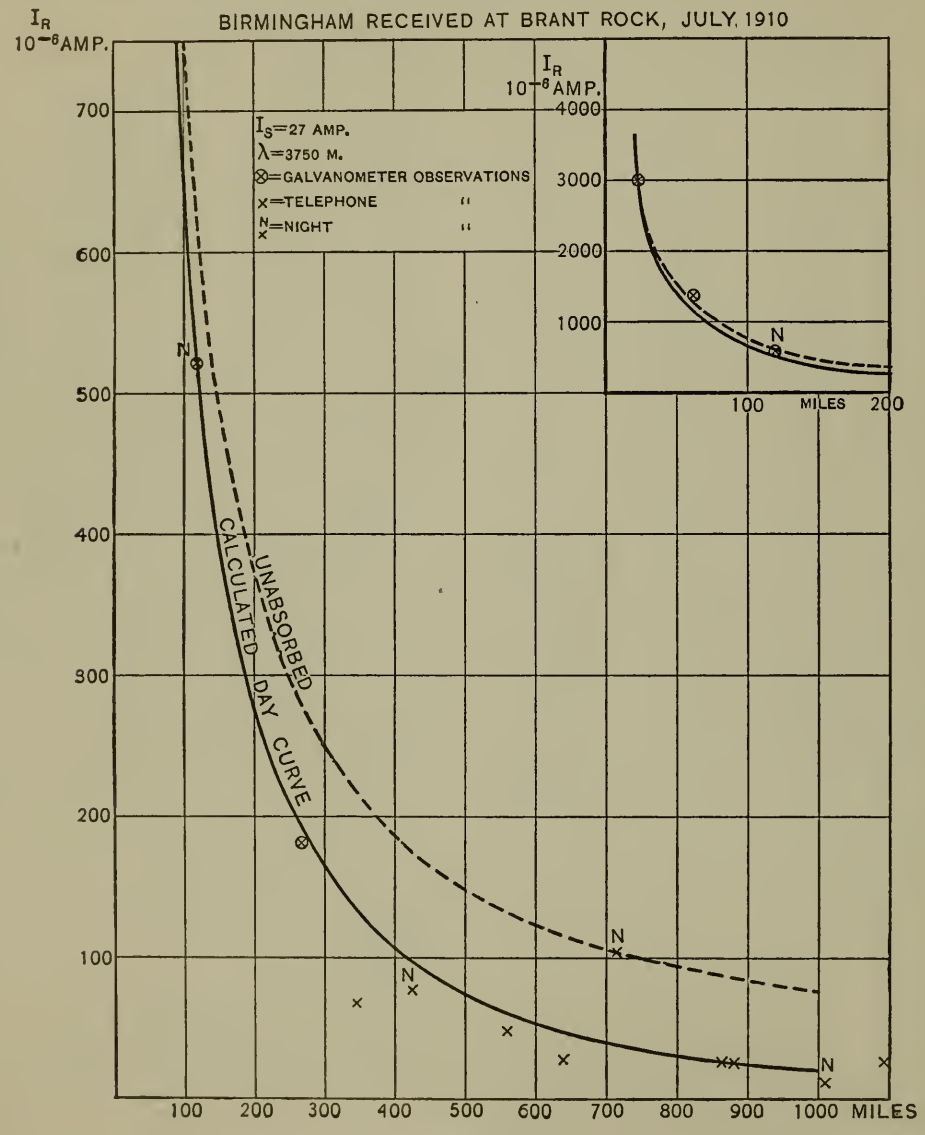

Fig. 4

probably be due to errors of observation, since it is not observed that the remarkable strength of signal is reciprocal between the two stations. If the observations are genuine, however, it would perhaps indicate some kind of reflection from the upper layers of the atmosphere.

THE CAUSE OF THE ABSORPTION

According to the calculations of Zenneck,[10] the conductivity of air at moderate heights can not explain the magnitude of the observed absorption, neither can the sea-water absorption be of

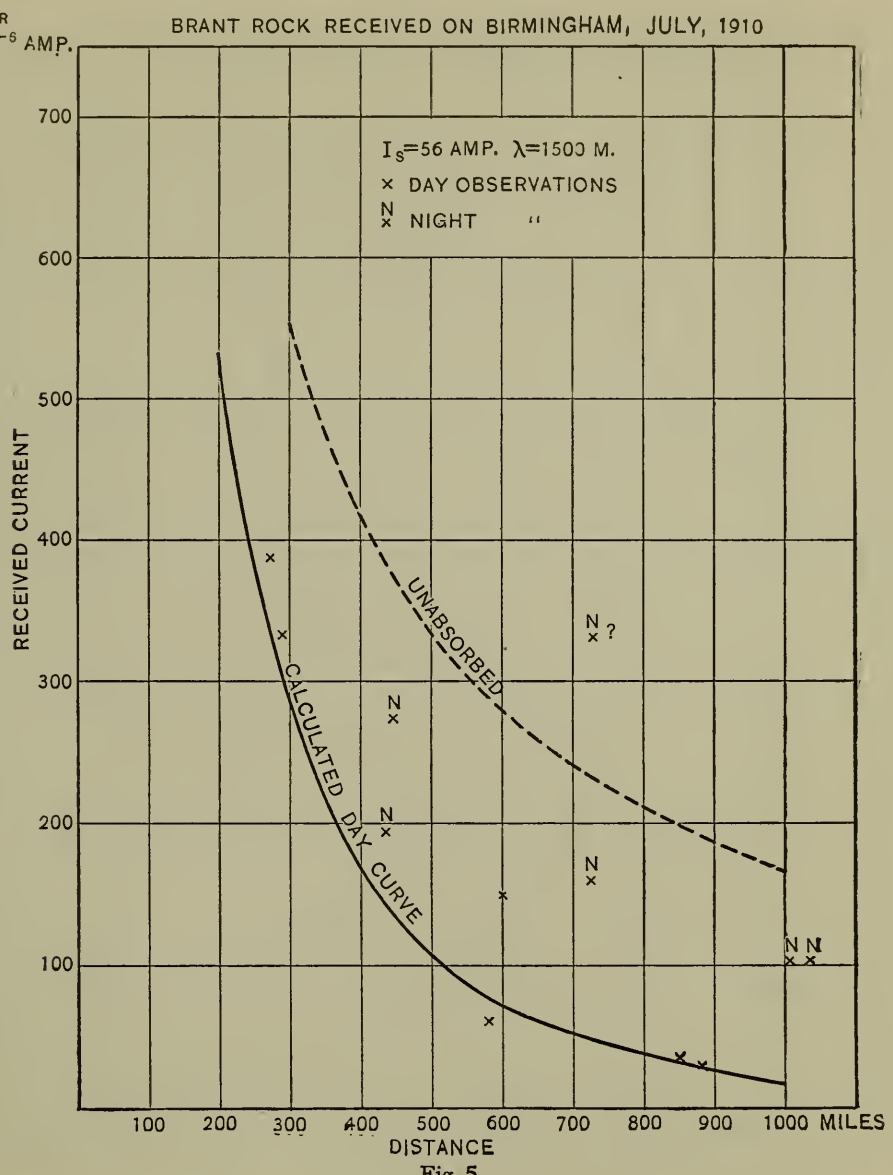

Fig. 5

the proper magnitude, according to the same author. But as the wave front at any considerable distance from the sending station must extend far into the upper layers of the atmosphere, it does not seem improbable that this is the region of absorption. If

[10] Zenneck, Ann. d. Phys., **23**, p. 846; 1907.

the conductivity is increased by the sun's rays at these heights, this would also explain the differences in the strength of the day and night signals. The observations would indicate, if this explanation is true, that the excessive ionization may, especially in

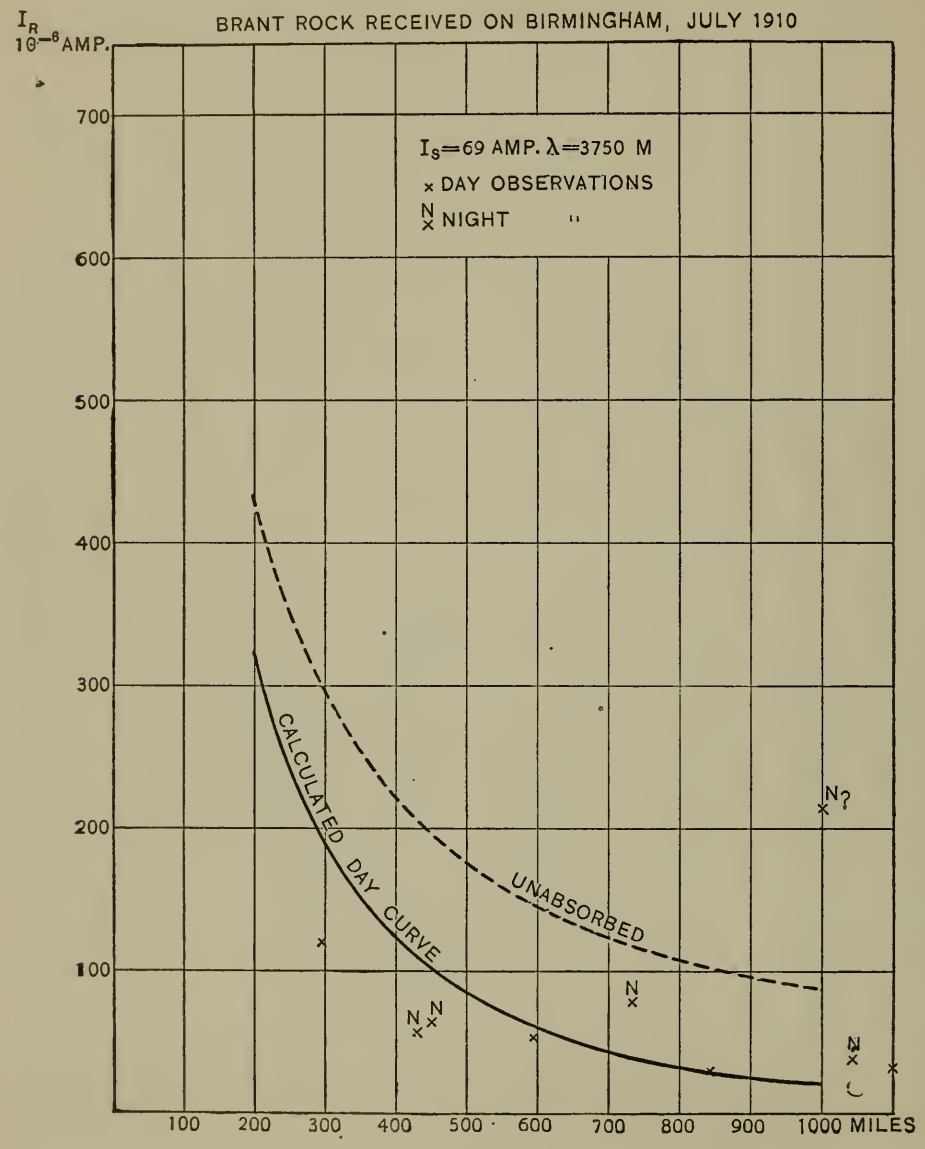

Fig. 6

summer, persist through many nights. The general experience of wireless telegraphy would indicate that during the colder months the absorption dies out more uniformly at night. The day absorption appears from the data obtainable to be fairly uniform

throughout the year, at least in the portion of the ocean covered by our observations, although there are undoubtedly variations at times, as has been already mentioned in regard to the *Birmingham*-Brant Rock signals. There are well-authenticated instances

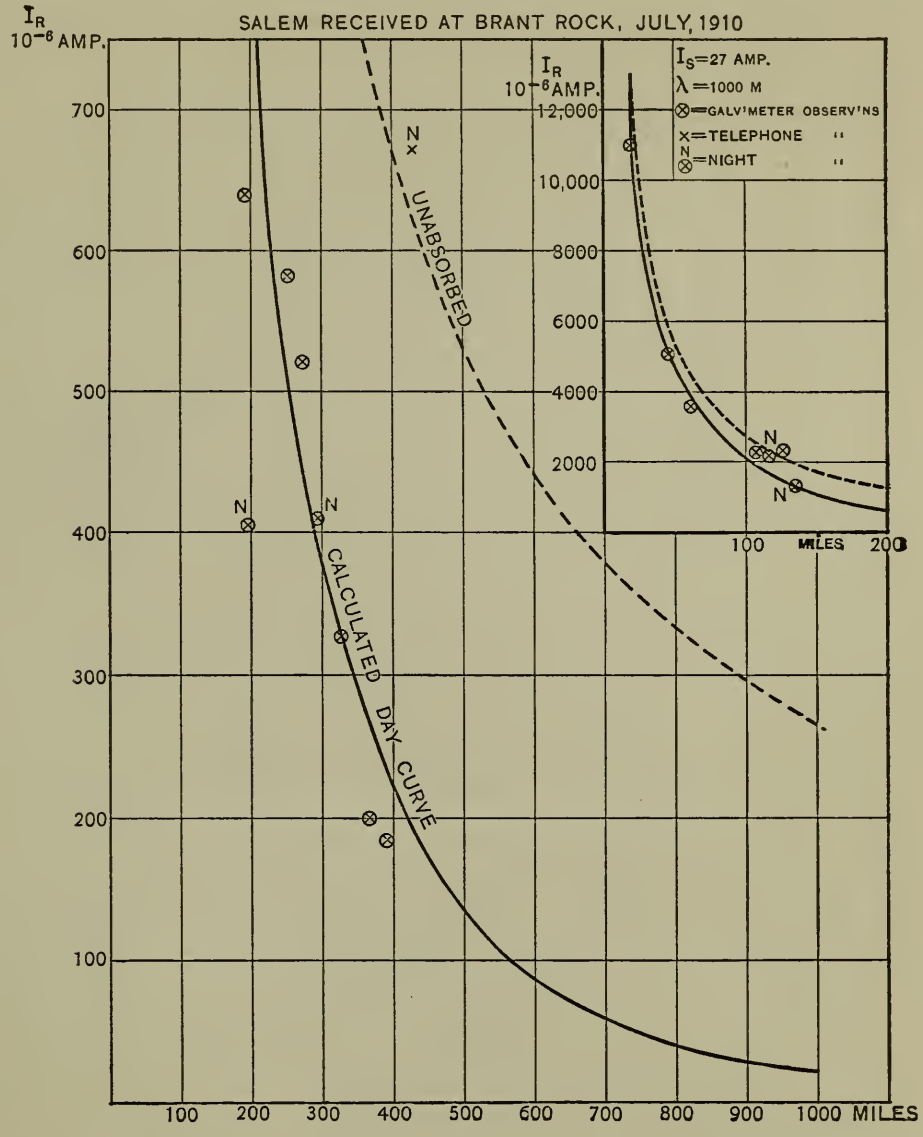

Fig. 7

when, for a day or two, the absorption seems to nearly disappear in the daytime. A case in point is that of the long-distance day signals between the *Birmingham* and Brant Rock on the return voyage from Liberia mentioned on page 351.

SUPPLEMENTARY MEASUREMENTS

PROPORTIONALITY OF SENDING AND RECEIVING CURRENTS

It was thought possible that when the antennas were used with the highest power, especially at the longer wave lengths, there might be losses of energy, either by brushing or by leakage over the insulators, which might destroy the proportionality between

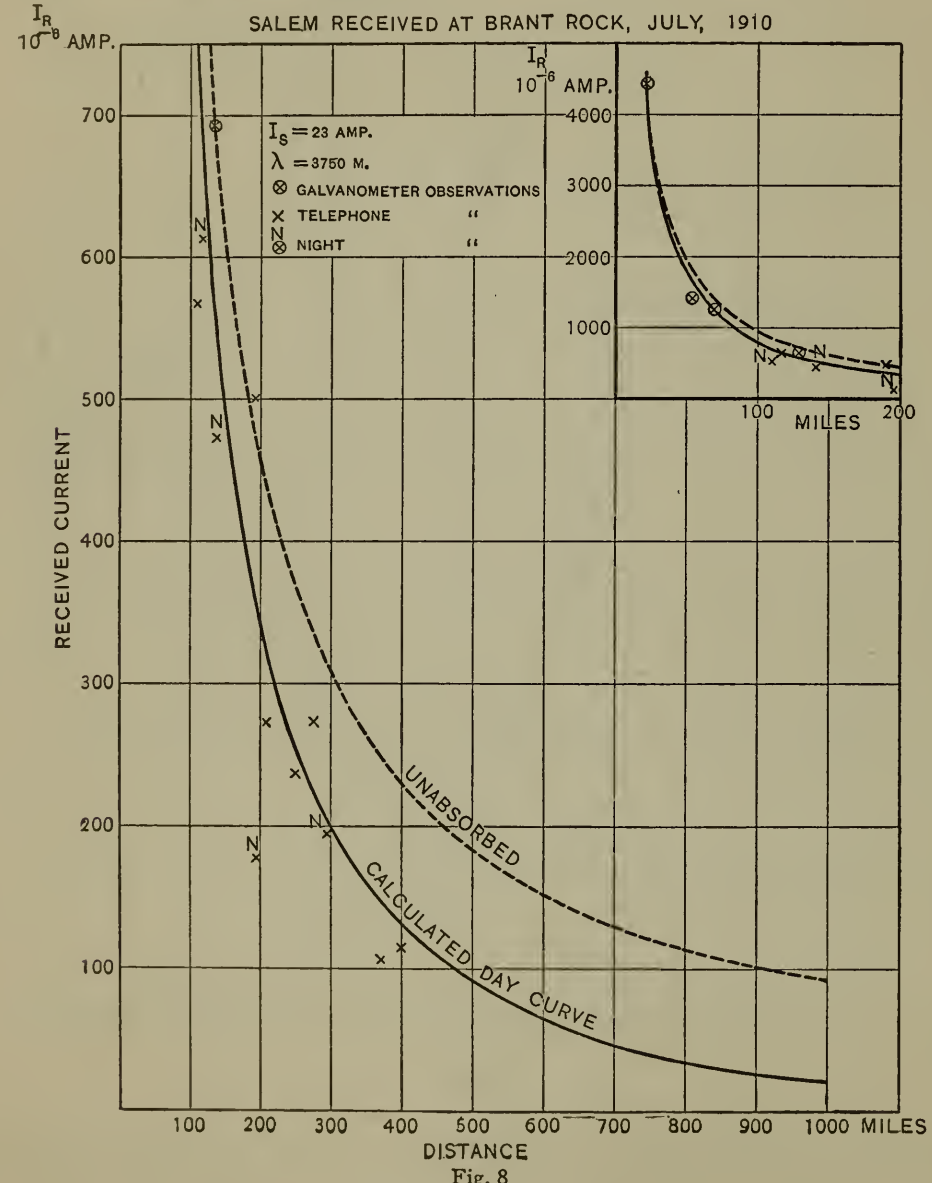

Fig. 8

sending antenna current and received antenna current. To settle this question, the station at Brant Rock sent with varying powers at a wave length of 3750 meters. The signals were received on the antenna at the Bureau of Standards at Washington, D. C.,

380 miles away. The receiving antenna was of the harp form, 180 feet high at top, 40 feet high at bottom, and 18 feet wide, with 8 wires. The capacity was approximately 0.0012 microfarad. A chalcopyrite zinkite rectifier, with a sensitive galvanometer, was connected in a tuned secondary circuit coupled to the antenna

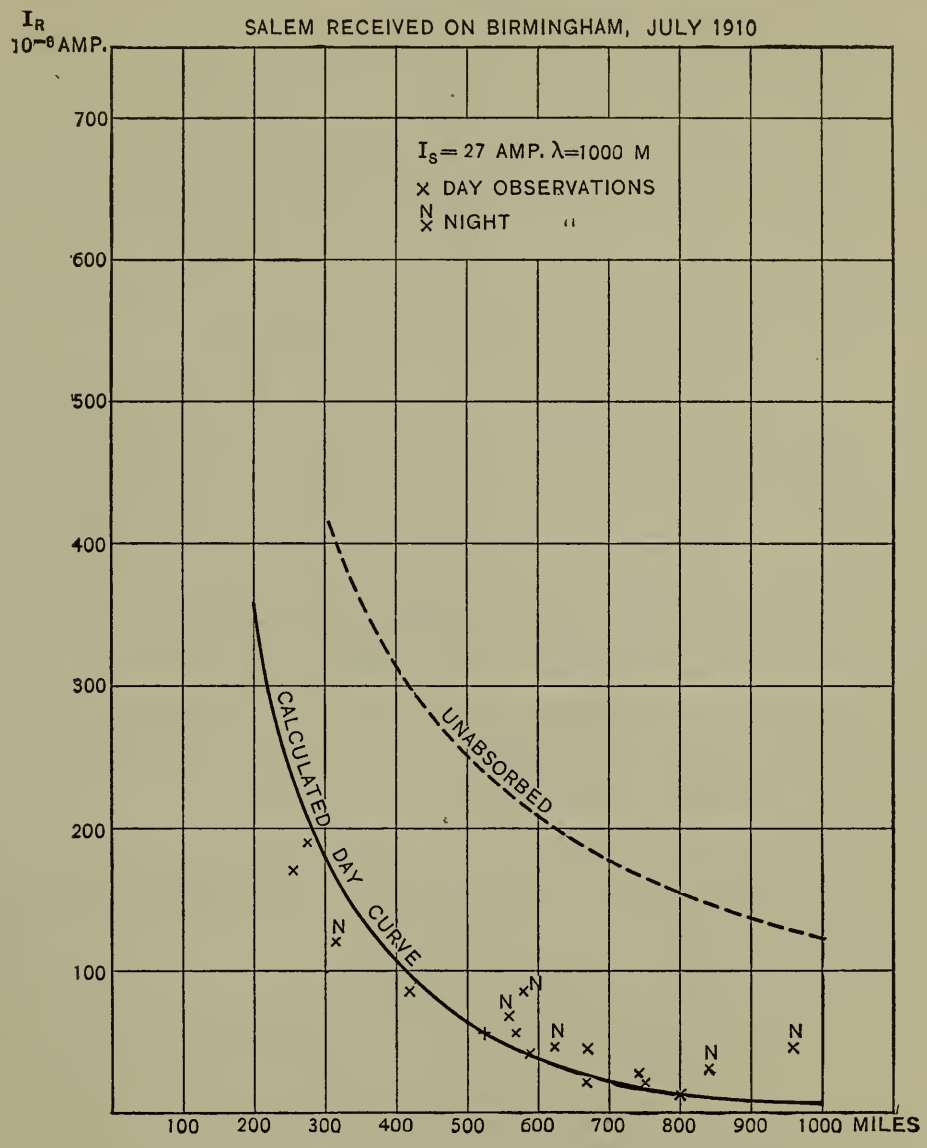

Fig. 9.

inductance so as to give maximum deflection, the circuits being those shown under circuit A in Fig. 1. The results are shown in the curve of Fig. 11. The galvanometer deflections are proportional to the square of the current, hence the square roots of the deflections expressed in microamperes of received antenna current are compared with the sending antenna current at Brant Rock.

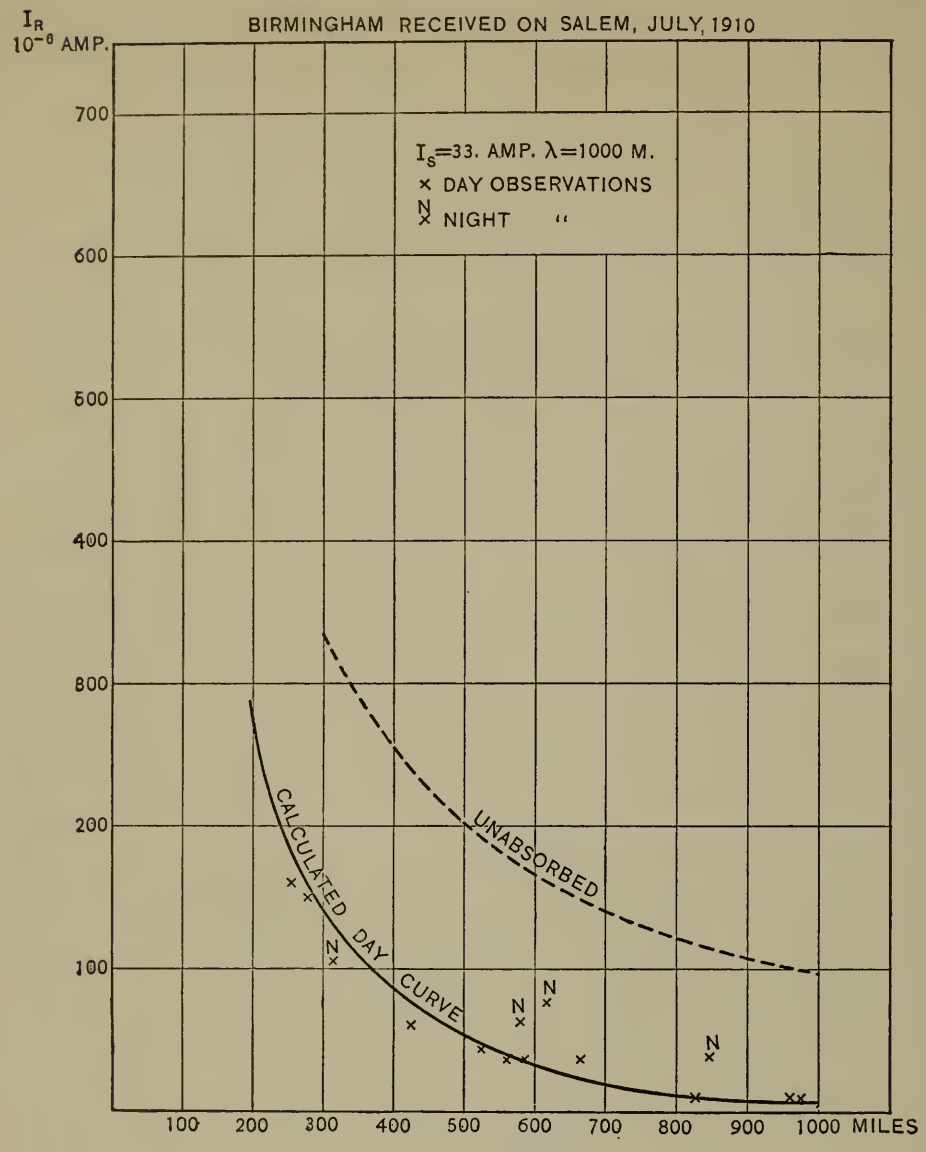
BIRMINGHAM RECEIVED ON SALEM, JULY, 1910
I_R 10^{-6} AMP.
I_s=33. AMP. λ=1000 M.
× DAY OBSERVATIONS
N × NIGHT "
UNABSORBED
CALCULATED DAY CURVE
700
600
500
400
800
200
100
100 200 300 400 500 600 700 800 900 1000 MILES

Fig. 10

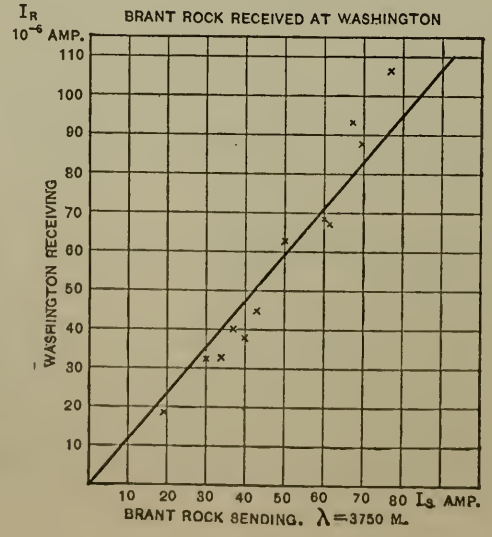
BRANT ROCK RECEIVED AT WASHINGTON
I_R 10^{-6} AMP.
WASHINGTON RECEIVING
110
100
90
80
70
60
50
40
30
20
10
10 20 30 40 50 60 70 80 I_s AMP.
BRANT ROCK SENDING. λ=3750 M.

Fig. 11

The proportionality is fairly good. It is possible that in the changes of adjustment of the circuits at Brant Rock the tuning became somewhat deranged, or that the change of the coupling at Brant Rock produced a change in the damping of the waves, which was not compensated for by a change in the coupling at Washington. A few observations were taken at Brant Rock on signals sent from the *Birmingham* when coming into Newport, R. I., both at wave lengths of 1000 meters and 3750 meters. From these it was concluded that there was no marked overloading of the sending antenna, although there were slight indications in this direction at the wave length of 3750 meters.

THE EFFECT OF ANTENNA HEIGHT AND WAVE LENGTH IN SENDING AND RECEIVING

At the close of the test with the scout cruisers, a flat top antenna was erected at Plymouth, 11 miles from Brant Rock, for the purpose of investigating the relationship of height of antenna and wave length to sending and receiving. Except for a narrow sand spit the whole path of the waves between the two stations lay over water. The antenna was swung between two noninsulated steel masts in order to reproduce as fully as possible the conditions on board ship. The Plymouth antenna had a length of 110 feet and consisted of 11 wires 2 feet apart. The capacity was approximately 0.001 microfarad. The Plymouth station was furnished with a 2-kilowatt, 500-cycle Fessenden sending set, and a somewhat larger 500-cycle set used at Brant Rock. The currents were measured at both stations by means of 15-ohm thermoelements with galvanometers as described on page 317. The experiments were begun by my assistants, but were completed by Dr. Cohen of the National Electric Signalling Co.

SENDING

Table XII gives the results of observations taken by Dr. Cohen and his assistants, Plymouth being the sending station and Brant Rock the receiving. This table is for the most part self-explanatory. The deflections of the galvanometer connected to the thermoelement are proportional to the square of the current, so that the square roots of these deflections are taken as proportional to the current itself. The deflections are in arbitrary units. For

comparison, the square roots of the deflections were reduced to a uniform sending antenna current. These values are given under I_R in the next to the last column, while the last column gives this quantity divided by the height. Although there is considerable

TABLE XII

Plymouth Received at Brant Rock

λ=3900 m

Antenna Plymouth h	I_S	Deflection Receiving D	$I_R = \sqrt{D}$ reduced to I_S=4.7 amp.	$\frac{I_R}{h}$
80 ft.	4.7 amp.	62.3	7.9	0.099
70	4.6	34	5.95	.085
60	4.7	30.3	5.5	.092
50	4.85	24.1	4.76	.095
40	4.9	15.6	3.79	.095
30	5.1	7.4	2.51	.084

λ=1585 m[1]

h	I_S	D	I_R (I_S=5.5 amp.)	$\frac{I_R}{h}$
70 ft.	5.5 amp.	292	17.1	0.244
60	5.5	198	14.1	.235
50	5.65	110.7	10.2	.204
40	6.05	84	8.32	.207
30	6.3	62	6.88	.229

h=80 ft.
35 ohms added in receiving antenna

λ	I_S	D	I_R (I_S=4.2 amp.)	$I_R \times \lambda$
3900 m.	4.2 amp.	4.0	2.0	7800
2980	4.5	8.3	2.69	8030
2400	4.75	13.6	3.26	7830
1985	5.1	26.3	4.22	8400

Shorter wave lengths were not used on account of the long natural wave length of the Brant Rock station.

variation in the values of this column it is evident that there is no systematic variation, and for the individual wave lengths we must consider that the received current is proportional to the height of the sending flat-top antenna. The receiving antenna was tuned by means of a variable inductance in series with the thermo-element.

In the last section of Table XII the results show the variation with wave length, and in this case the equivalent received current is multiplied by the wave length and the product is seen to be approximately constant. Thirty-five ohms was introduced into the receiving antenna to nullify the changes in the resistance of the inductance during the process of tuning. This table shows that the received antenna current is proportional to the height of the sending attenna and inversely proportional to the wave length.

RECEIVING

Table XIII gives similar data in regard to the Plymouth antenna used for receiving, the sending station being Brant Rock. This table shows that the same relationship holds for receiving as for sending; that is, for a constant sending antenna height and current the received current is proportional to the height of the receiving antenna and inversely proportional to the wave length.[11]

While it appears that the sending and receiving relations for a flat-top antenna are reciprocal, this is apparently not the case for an umbrella antenna. It is seen from the observations that the scout cruisers, sending with 10 kilowatts, were received at Brant Rock with almost the same strength as that with which Brant Rock, sending with 60 kilowatts, was received on the cruisers. Comparing the strength of the sending and receiving currents, it appears that the umbrella antenna at Brant Rock for sending is only equivalent to a flat-top antenna 170 feet high, which is not far from the height of the lower ends of the umbrella, while for receiving its equivalent height is much greater. A few experiments have also been made on an umbrella and flat top at Plymouth, which also showed that an umbrella is a better receiver than radiator.

[11] This will not strictly hold in the case where the radiation resistance of the receiving antenna is comparable with the rest of the antenna resistance. See R. Ruedenberg, Ann. d. Phys., **25**, p. 446; 1908.

TABLE XIII

Brant Rock Received at Plymouth

λ=4000 m

Antenna Plymouth h	I_S	Deflection Receiving D	$I_R = \sqrt{D}$ reduced to I_S=7.0 amp.	$\frac{I_R}{h}$
80 ft.	7.0 amp.	8.4	2.90	0 0362
70	10.0	12.4	2.46	.0352
60	9.4	8.0	2.10	.0350
50	9.75	6.0	1.76	.0352

λ=1980

h	I_S	D	I_R (I_S=7.4 amp.)	$\frac{I_R}{h}$
80 ft.	7.4 amp.	26.0	5.1	0.0637
70	7.6	24.0	4.77	.0682
60	11.1	41.1	4.28	.0713
50	10.9	22.6	3.22	.0644
40	10.4	15.5	2.80	.0700

h=70 ft.
35 ohms added in receiving antenna

λ	I_S	D	I_R (I_S=10 amp.)	$I_R \times \lambda$
4000 m	10.0 amp.	4.3	2.07	8300
3550	9.1	4.8	2.41	8560
2980	8.6	6.0	2.85	8500
2510	9.9	12.9	3.63	9110
1984	7.6	10.0	4.16	8240

Uniting the experimental data contained in the last two tables with the data obtained from the experiments with the cruisers, we may write an equation which will cover the normal day received current over salt water through 25 ohms for two stations with flat-top antennas of any height, with any value of sending current and any wave length, provided the sending station is so coupled as to give but one wave length.

We may write this equation as follows:

$$I_R = 4.25 \frac{I_S h_1 h_2}{\lambda d} e^{-\frac{\alpha d}{\sqrt{\lambda}}} \quad (3)$$

where I_R represents the current received through 25 ohms resistance, I_S the sending current, h_1 the height of one antenna, h_2 that of the other, d, the distance between the stations, and λ the wave length, where all the lengths are taken in kilometers and the currents in amperes. α is the absorption coefficient, which in our experiments was found to be equal to 0.0015. This disregarding the absorption term $e^{-\frac{\alpha d}{\sqrt{\lambda}}}$, corresponds in form to the Herzian equation for the electromotive force in a vertical resonator at a distance from the oscillator.

TABLE XIV

Calculated Relation between Antenna Current and Distance for Two Ships with Antenna Heights of 130 Feet

$\lambda = 1000$ m

Antenna Current I_S	Working Distance 40.10^{-6} amp.		Extreme Distance of Audibility 10.10^{-6} amp.	
	Day	Night (Zero Absorption)	Day	Night (Zero Absorption)
1 amp.	75 miles	90 miles	200 miles	360 miles
2	135	180	300	720
3	180	270	375	1080
5	235	450	475	1800
7	280	630	550	2520
10	345	900	630	3600
15	420	1350	725	5400
20	475	1800	790	7200
25	525	2250	840	9000
30	565	2700	900	10800
40	630	3600	970	14400
50	685	4500	1025	18000
60	725	5400	1150	21600

In our formula the constant 4.25 applies strictly only to ship antennas with the same losses due to masts, rigging, etc., both in sending and receiving, as found on the scout cruisers. On other ships the value of the constant might probably differ by as

much as 30 per cent under ordinary conditions. This difference in the value of the constant does not, however, make a very great difference in the range of communication, although for short distances it would make a considerable difference in the loudness of signal. To show the variation in range of communication with different antenna currents, Table XIV is given, showing the range of communication between two flat top antennas 130 feet high at a wave length of 1000 meters for various values of the sending antenna current, assuming that 40×10^{-6} ampere assures good communication. A quarter of the indicated current would produce audible signals under favorable conditions. The table shows how very slowly the range increases with increasing sending current. Increasing the current from 30 to 60 amperes increases the distance only from 565 miles to about 725 miles, while even with 10 amperes, corresponding to a moderately efficient 2-kilowatt set, 345 miles is easily reached.

In columns 3 and 5 are given the distances attainable for regular communication and audibility on the assumption that there is no atmospheric absorption; that is, the extreme range of night communication.[12]

TABLE XV

Good Working Distance and Sending Current for Two Stations with Flat Top Antennas 450 Feet High

Nautical Miles	λ=1000 m	λ=2500 m	λ=3750 m	λ=6000 m
1000	15 amp.	13.5 amp.	15 amp.	17 amp.
1250	38	27	27	30
1500	91	49	44	46
1750	200	95	77	74
2000	490	155	122	105
2250		245	200	160
2500		470	314	235
2750			500	335
3000			775	500

In Table XV is given the estimated day range of two large stations with flat-top antennas 450 feet high for various antenna

[12] Excluding the possibility of the effects of reflection from the upper atmosphere.

currents and four wave lengths. The table shows the great advantage of long wave lengths for very distant stations. It is seen that for good communication at a distance of 2500 miles not less than 240 amperes [13] must be used at a wave length of 6000 meters, though one-fourth of this would be audible.

For the purpose of easily calculating the probable day working distance for various sending currents, heights, and wave lengths according to equation (3) Tables XVI and XVI-A are given. Table XVI gives the current which may be expected to be received through 25 ohms for an antenna height at both stations of 130 feet and a sending antenna current of 30 amperes. Table XVI-A gives the sending currents which will be required for various heights of the sending and receiving antennas h_1 and h_2 to give the values of the received currents as shown in Table XVI. To determine the current which will be received for any antenna height, wave length, and distance for a given sending current, multiply the value, given in Table XVI for the given distance and wave length, by the given current, divided by the value of I_s in Table XVI-A for the given antenna heights.[14] In Table XVI it may be assumed that 40×10^{-6} ampere insures good communication and that 10×10^{-6} ampere is just audible.

---

[13] From the experience of the Marconi transatlantic stations it would appear possible that for the same antenna current the distances given in the table could be obtained with a smaller antenna height provided a bent antenna were used.

[14] Example: If $h_1=200$ feet, $h_2=130$ feet, $\lambda=600$ meters, distance=500 miles, and $I_S=12$ amperes, then $I_R=60.2\times12/19.5=37.0\times10^{-6}$ ampere. The above tables have been given in this convenient form for calculation largely with the hope that they will be tested by the experience of the various wireless companies. It is very common in wireless stations to have an antenna meter for the measurement of the sending current. When this is used with a shunt, the multiplying value of the shunt for the given frequency may easily be obtained by connecting a like unshunted hot-wire meter in the antenna in series with the regular instrument and sending with reduced power so that the needle of the unshunted meter just remains on the scale. The ratio of the readings of the two meters then gives the multiplying value. When only one meter is available an approximate calibration may be obtained by sending with reduced power and observing the reading of the meter without the shunt and then with the shunt connected. Of course this calibration must be carried out with the same wave length used in regular work. The range of good daylight communication with another flat-top antenna of known height over sea water can be compared with the values in the table for the given wave length, distance, and sending current, provided the sending station radiates but a single wave length. If the equation is correct, the tables should indicate a current of from 20 to 40 microamperes.

TABLE XVI

Currents in Microamperes Received Through 25 Ohms for a Sending Current of 30 Amperes and Sending and Receiving Flat Top Antenna Heights of 130 Feet, over Salt Water

[Calculated from Eq. 3]

Nautical Miles	d Km	λ=300 m		λ=600 m		λ=1000 m		λ=1500 m		λ=2500 m		λ=3750 m		λ=6000 m	
		K=6.67.10⁵		K=3.33.10⁵		K=2.10⁵		K=1.33.10⁵		K=8.10⁴		K=5.33.10⁴		K=3.33.10⁴	
		$\frac{K}{d}$	I_R	$\frac{K}{d}$	I_R	$\frac{K}{d}$	I_R	$\frac{K}{d}$	I_R	$\frac{K}{d}$	I_R	$\frac{K}{d}$	I_R	$\frac{K}{d}$	I_R
20	37	18000	16300	9000	8350	5400	5100	3590	3430	2160	2080	1440	1400	900	880
50	92.5	7200	5600	3600	3020	2160	1880	1435	1282	864	790	576	536	360	340
100	185	3600	2170	1800	1270	1080	817	720	573	431	361	28o	249	180	161
200	370	1800	650	900	433	540	310	359	228	216	152	144	108	90	71.8
300	556	1200	263	600	205	360	156	240	122	144	85	96	62.4	60	42.7
400	740	900	116	450	107	270	89	180	73	108	53.6	72	40.8	45	28.6
500	925	720	55.4	360	60.2	216	53.8	144	46.3	86.4	35.9	57.6	28.2	36	20.5
600	1110	600	27.6	300	34.8	180	34.2	120	31.1	72	25.3	48	20.4	30	15.2
800	1480	450	7.72	225	12.8	135	14.7	90	14.8	54	13.1	36	11.5	22.5	9.06
1000	1850	360	2.27	180	4.97	108	6.7	72	7.5	43.1	7.42	28.8	6.77	18	5.80
1200	2220	300	0.66	150	2.0	90	3.24	60	3.95	36	4.36	24	4.34	15	3.89
1500	2780	240	0.12	120	0.54	72	1.10	48	1.58	28.8	2.04	19.2	2.25	12	2.18
2000	3700	180	0.0081	90	0.069	54	0.205	36	0.385	21.6	0.64	14.4	0.817	9	0.928
2500	4630	144	.....	72	0.0086	43.2	0.038	24.8	0.098	17.3	0.213	11.5	0.318	7.2	0.418
3000	5560	120	.....	60	0.0010	36	0.0079	24	0.031	14.4	0.073	9.1	0.129	6.0	0.198

TABLE XVI–A

Sending Currents Required to Produce Received Currents as Given in Table XVI for Various Antenna Heights

$h_1=h_2$	I_S amp.		$h_1=450$ ft.			$h_1=200$ ft.			$h_1=130$ ft.			$h_1=100$ ft.	
			h_2	I_S amp.		h_2	I_S amp.		h_2	I_S amp.		h_2	I_S amp.
32.5 ft.	480		32.5 ft.	34.5		32.5 ft.	78		32.5 ft.	120		32.5 ft.	156
65	120		65	17.3		65	39		65	60		65	78
100	51		100	11.3		100	25.3		100	39		130	39
130	30		130	8.7		130	19.5		160	24.4		160	31.8
160	19.8		160	7.1		160	15.8		200	19.5		200	25.4
200	12.7		200	5.6		300	8.5		300	13		300	16.9
300	5.66		300	3.76		450	5.65		450	8.7		450	11.3
450	2.5												

OTHER LONG-DISTANCE WORK

In all of the experiments with the cruisers excepting those carried on during the month of July the calculated received currents at unit distance were estimated from the ratio of the sending cur-

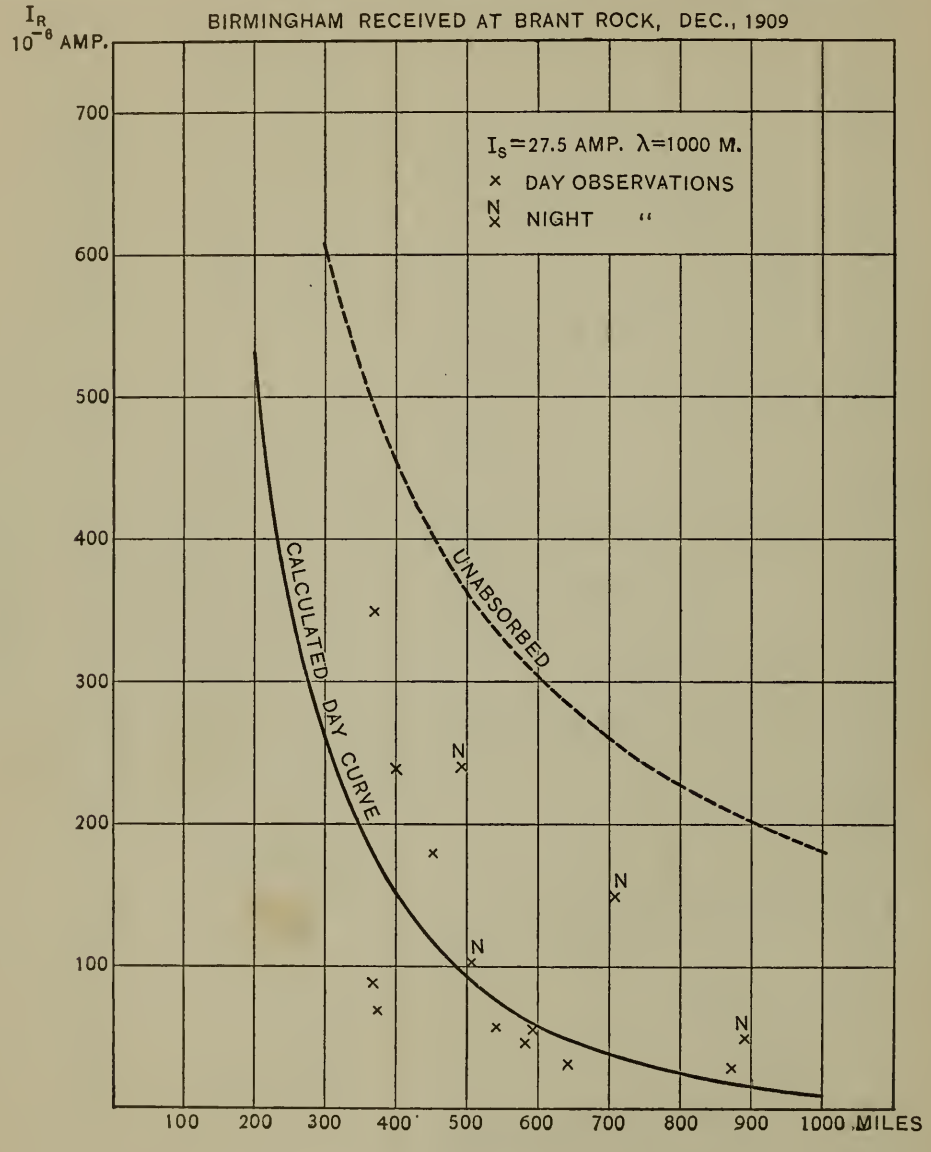

Fig. 12

rents to those observed at the corresponding stations in July, account of course being also taken of the change in antenna heights on the cruisers from 112 feet to 130 feet after the close of the December tests. This calculation is somewhat arbitrary, since there were many changes in the arrangement of the apparatus which very probably had an influence on the efficiency of the sets. Taking

all this into account, the results of these earlier tests can not by any means be considered to have the same weight as those in July. But as it is desirable to obtain all the light possible on the validity of the transmission formula, the following observations are given.

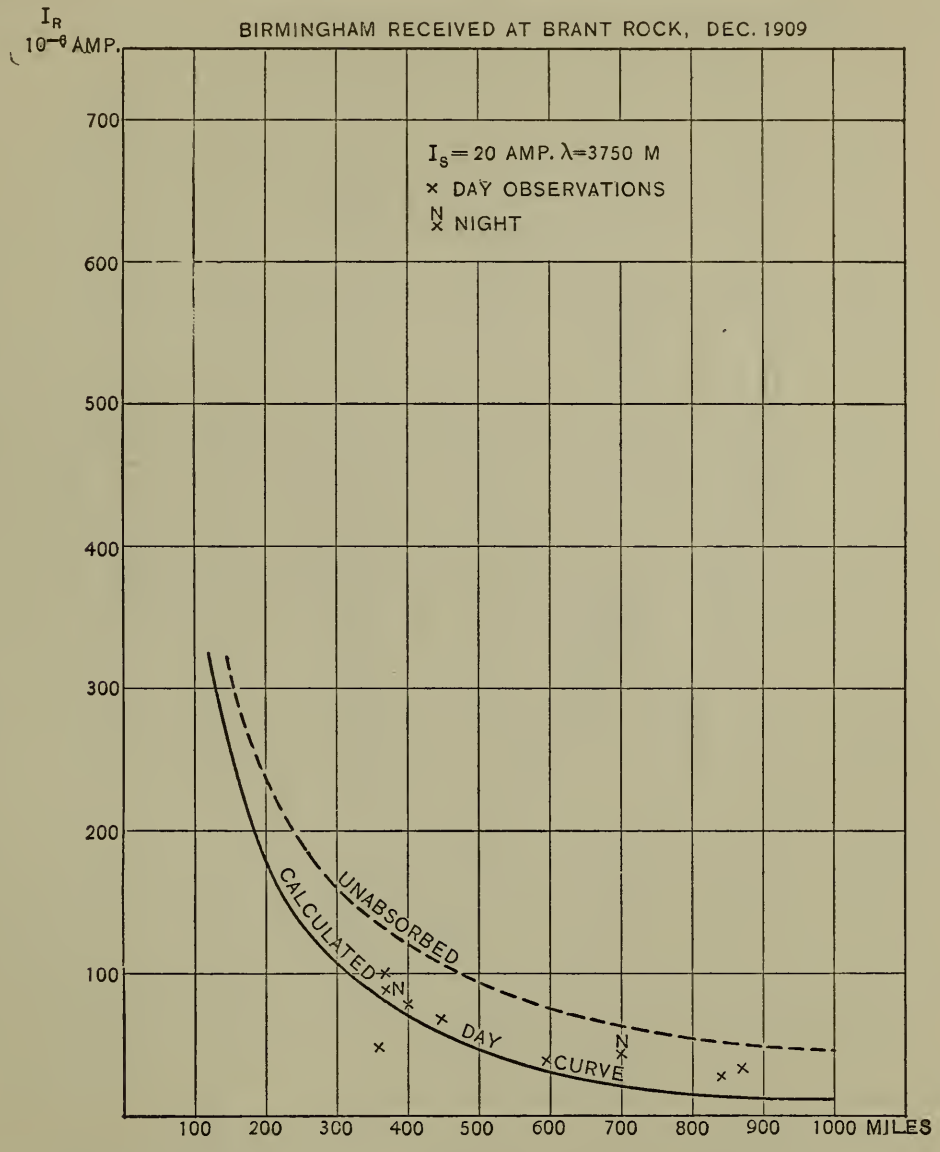

Fig. 13

DECEMBER EXPERIMENTS

The December experiments were made shortly after the installation of the sets on the cruisers, the *Birmingham* taking an easterly course from Provincetown, while the *Salem* sailed to the southward. At the greatest distance attained the two ships were distant from each other and from Brant Rock approximately 1000 miles.

The arrangement of the apparatus on the cruisers was highly unsatisfactory, largely on account of lack of space. In addition to this the weather was extremely tempestuous much of the time. In the light of all this, it is not surprising that the observed received currents fell below the calculated values.

The results are shown in the curves of Figs. 12 to 19.[15]

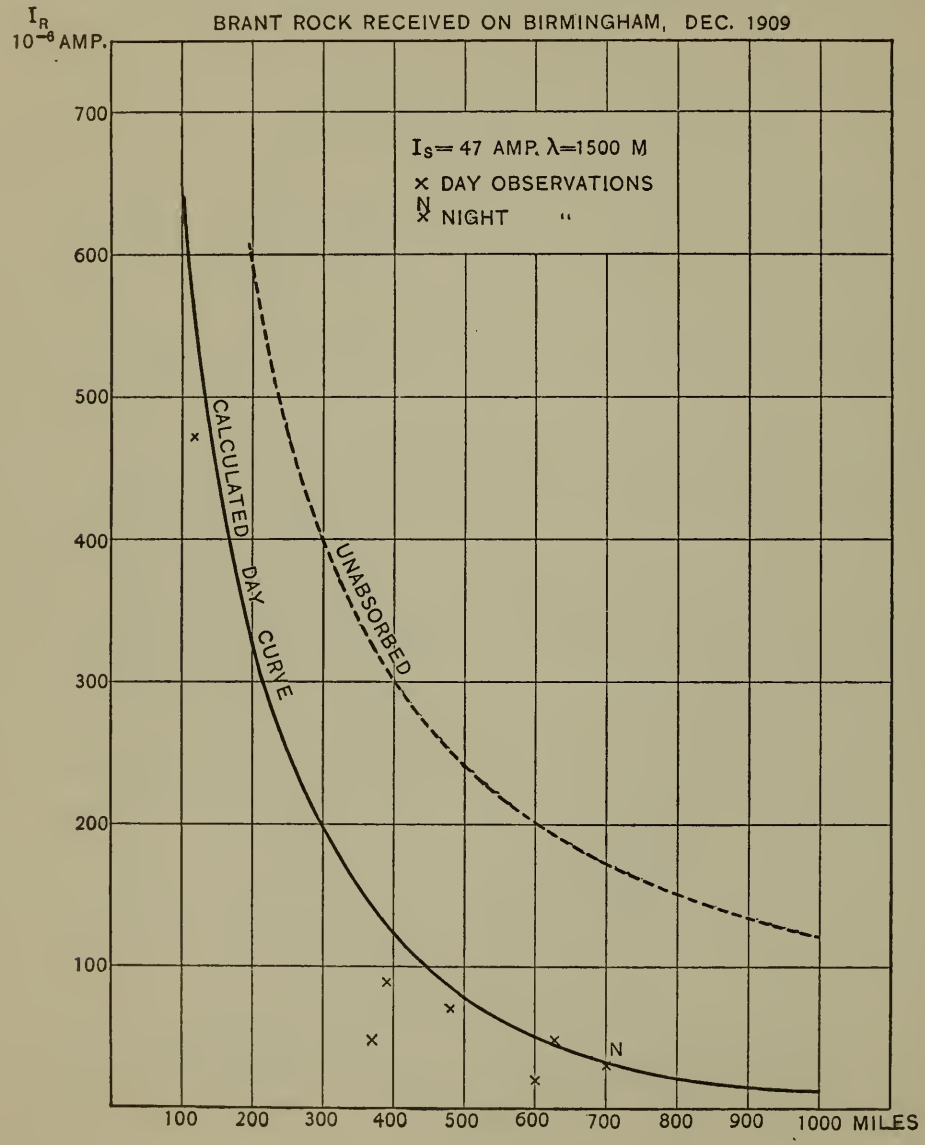

Fig. 14

MARCH EXPERIMENTS

In March the *Birmingham* was sent to Liberia, and during the voyage current measurements were made on the ship and at Brant Rock. The results are shown in Figs. 20 to 23.

[15] Neither of the cruisers was able to take any satisfactory measurements on the 3750-meter wave.

In some of the curves it is seen that the observations are exceedingly irregular, the day signals showing as much variation as the night signals during the July tests. In addition to the observations shown on the curves, faint day signals from the *Birmingham* were received at Brant Rock at a distance of 1325 miles, and again at 1720 miles, while the Brant Rock short wave was received

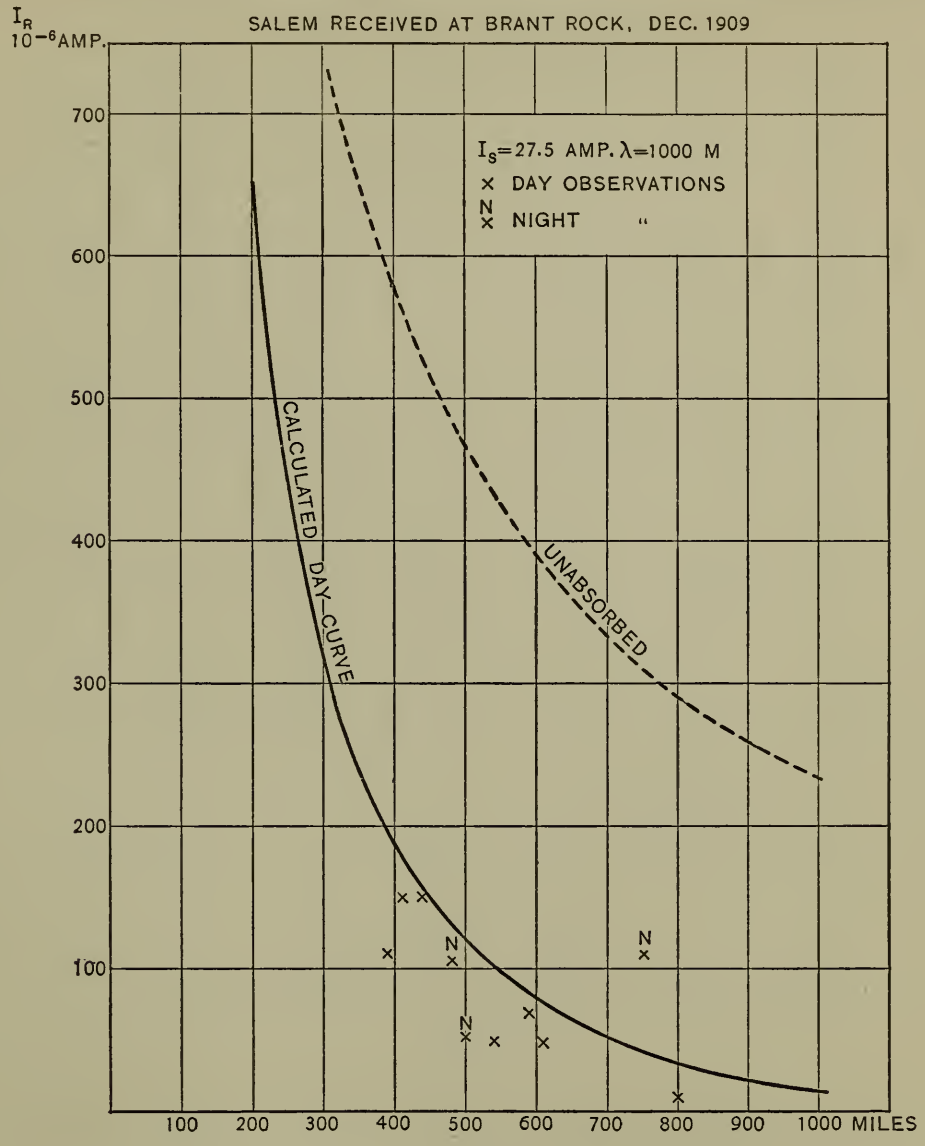

Fig. 15

faintly on the *Birmingham* at 1325 miles. All of these observations are beyond the range of calculated day audibility and show that there was an abnormally low absorption on these days.

Night signals during this voyage were also heard at times at great distances, the Brant Rock short wave being received on the

Birmingham at 2550 miles, while on the same night both waves from the *Birmingham* were received at Brant Rock.

MAY EXPERIMENTS

During the month of May the *Birmingham* returned from Liberia to Hampton Roads, and the results of the telephone observations taken during this voyage are shown in figures 24 to 27.

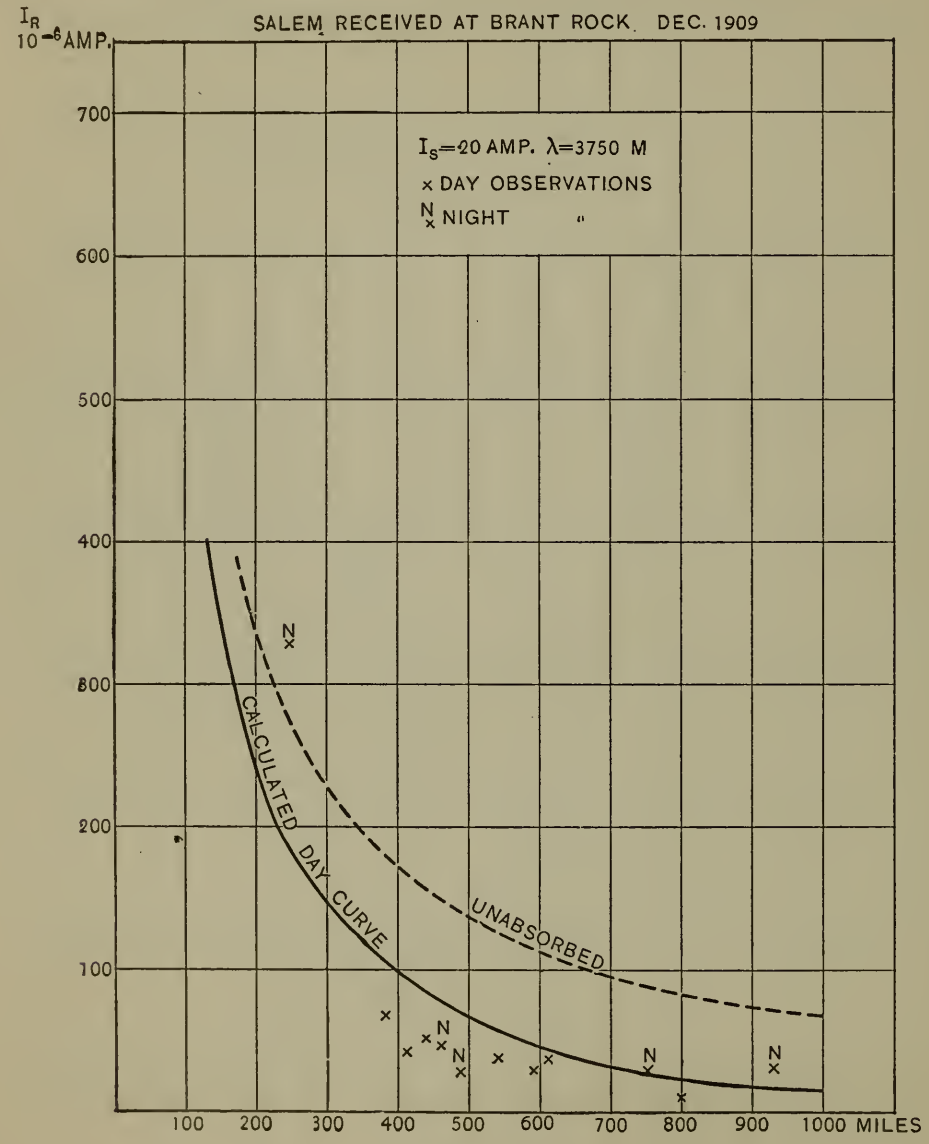

Fig. 16

Within the range covered by the curves the day observations are not as irregular as during the March voyage, although, as was also the case in March, some of the night observations lie above the curve calculated for zero absorption. As has already been said in describing the July experiments, these may be due to

errors of observation, or possibly to some kind of reflection from the upper atmosphere.[16] Beyond the range of the curves abnormal signals were again observed, faint day signals of the Brant

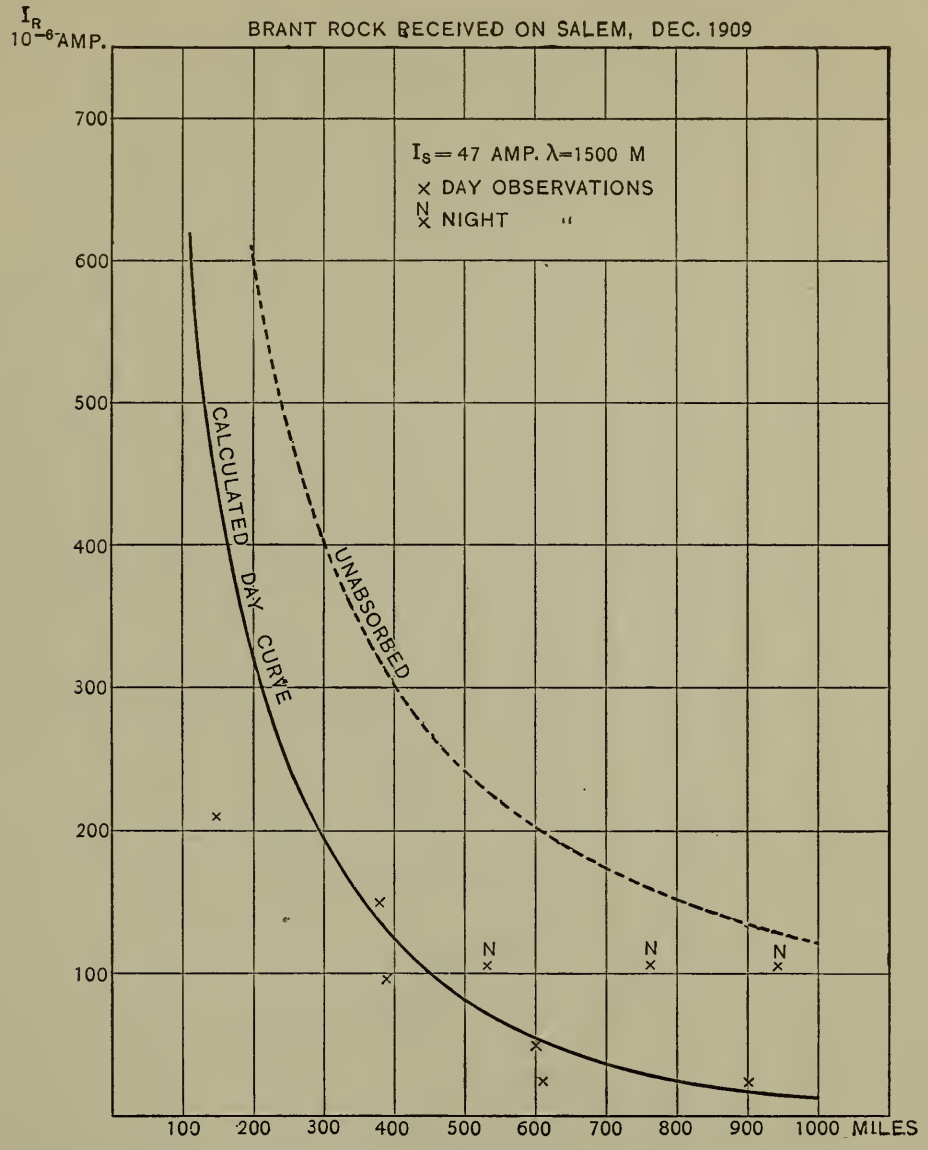

Fig. 17

Rock long wave being received on the *Birmingham* at 2330 miles,

[16] There can be no doubt that at times something of the nature of a reflection of signals from the upper atmosphere takes place. During the past winter the Norfolk station sending at a wave length of 1000 meters and with an antenna current of 10 or 12 amperes and antenna height below 200 feet was distinctly heard at night at the Mare Island Navy Yard in San Francisco, a distance of approximately 2000 nautical miles across the continent. Although it is possible that over sea water a clearing up of the atmospheric absorption would have explained this phenomenon, when we take into account the ground absorption which is probably independent of day and night and generally much greater than the atmospheric absorption, this explanation becomes untenable.

and the short wave at 1305 miles. Night signals from Brant Rock were first received at 2776 miles and were heard without interruption from that point on. Both waves from the *Birmingham* were received faintly in the daytime at Brant Rock at 2090

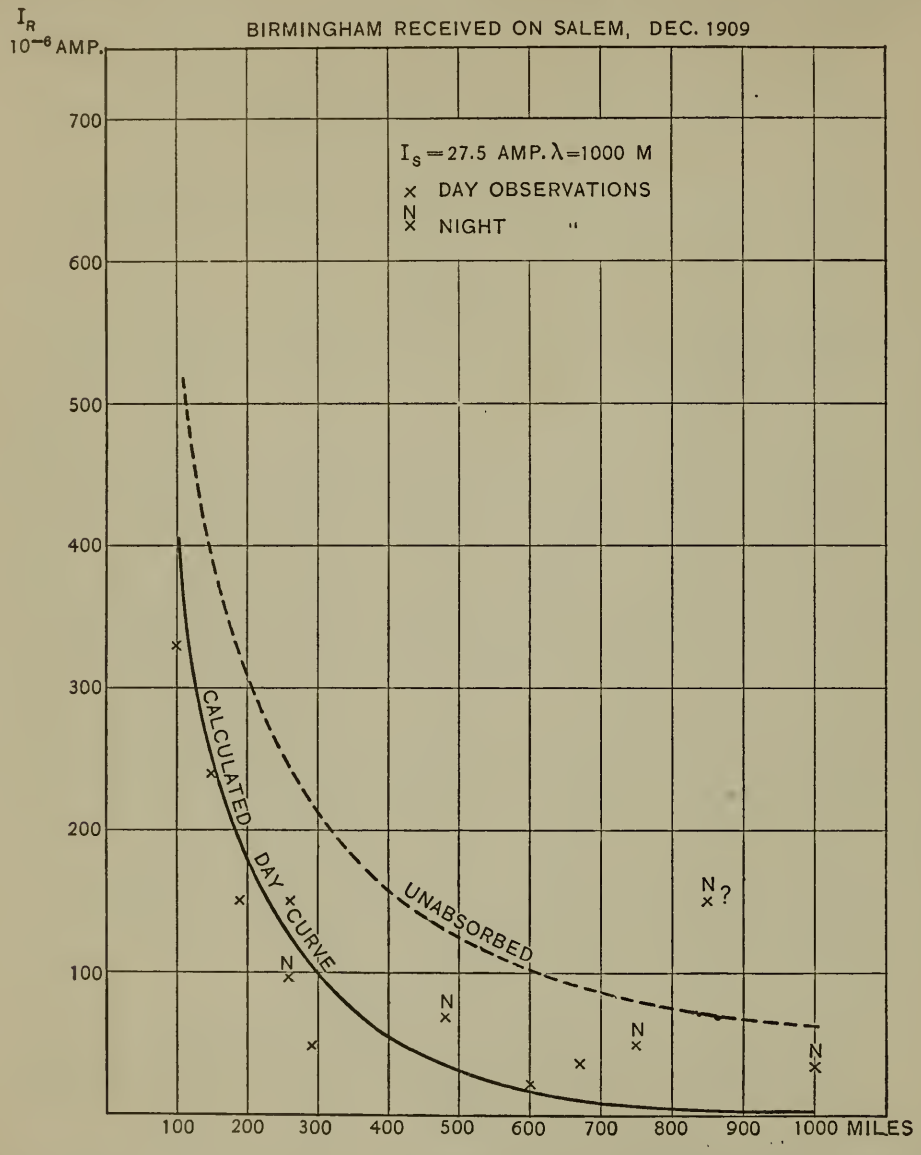

Fig. 18

miles, and the long wave again at 1315 miles, no other day signals being received until the distance was reduced to 815 miles. Night signals were received by Brant Rock from the *Birmingham* first at 2418 miles and continued nightly for the rest of the voyage, though very irregular in intensity. This remarkable continuation

of long range night communication must be considered exceptional so late in the year, though perhaps it would not be so considered in midwinter.

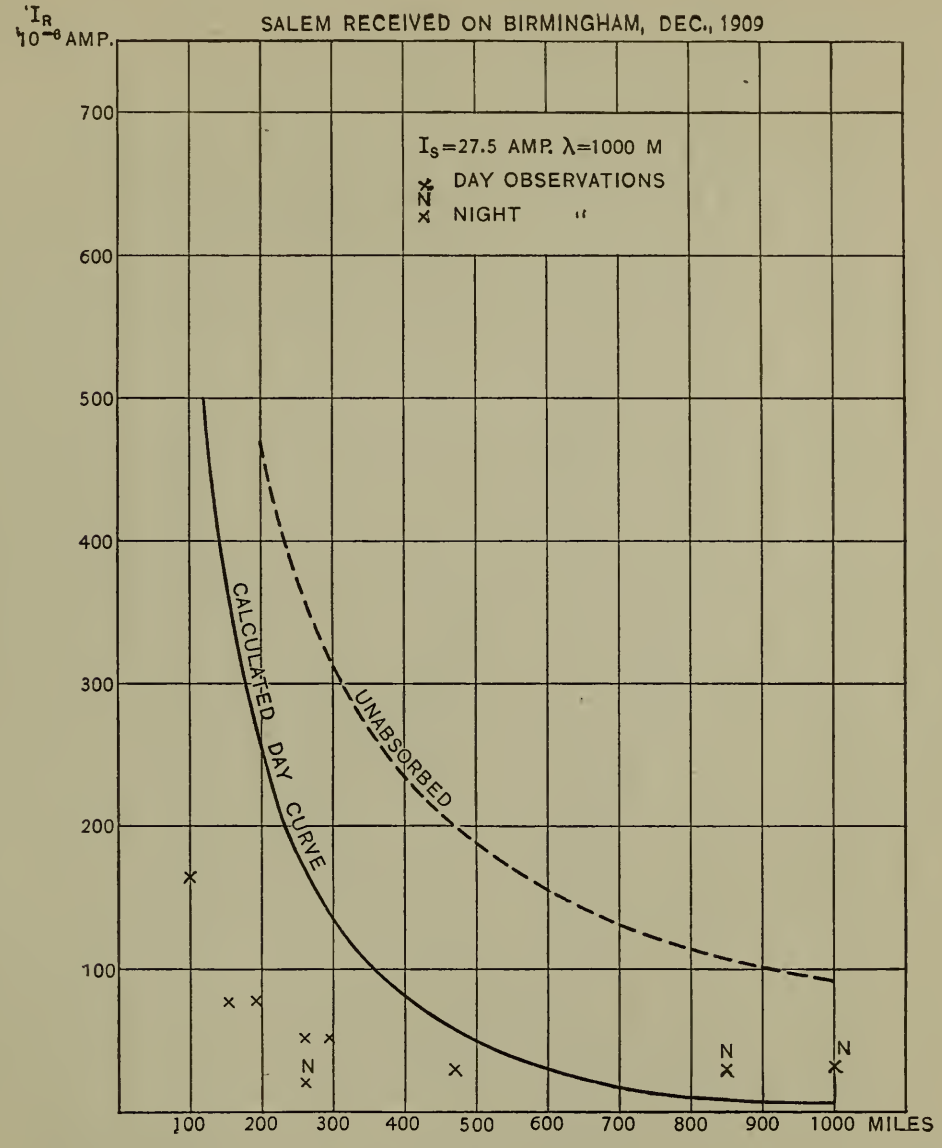

Fig. 19

TORPEDO-BOAT TESTS

In order to test the validity of equation (3) for very short wave lengths and small antennas, the torpedo boats *Stringham* and *Bailey* were detailed to carry out a series of tests in Chesapeake Bay during the month of November, 1910. The two boats were fitted

with small 120-cycle directly connected sending sets which, however, could be coupled loosely enough so that but one wave length was radiated. The flat-top antenna of the *Bailey* consisted of four wires 2 feet apart, 80 feet long, 32 feet above the water. The

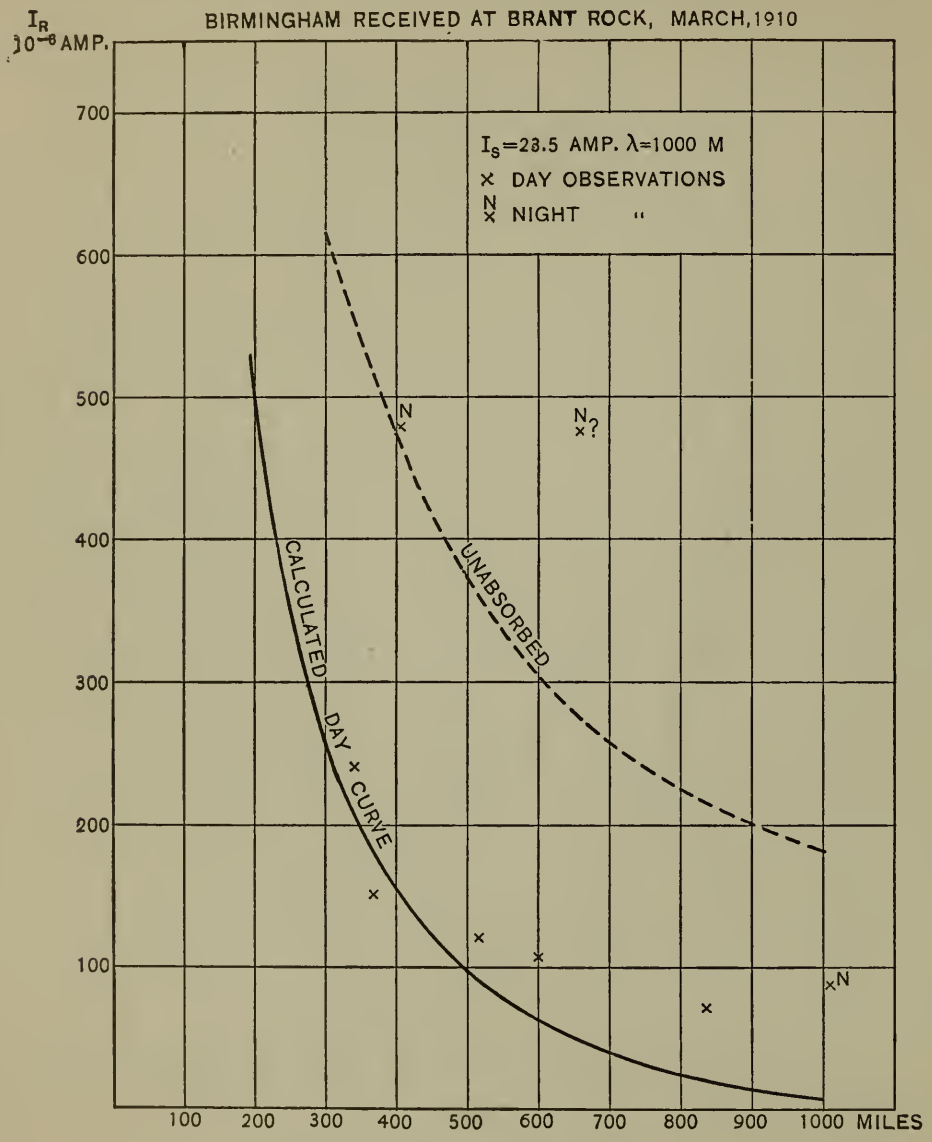

Fig. 20

antenna capacity was 0.000875 microfarad; the closed circuit condenser consisted of Leyden jars in air having a capacity of 0.015 microfarad. The length of the wave radiated by the *Bailey* was 280 meters.

The antenna of the *Stringham* consisted of four wires 2 feet apart, 135 feet long, and 48.5 feet above the water. Its capacity was 0.00134 microfarad. The closed circuit condenser was the same as that of the *Bailey*. The length of the *Stringham's* radiated wave was 340 meters. The receiving apparatus of both boats was of

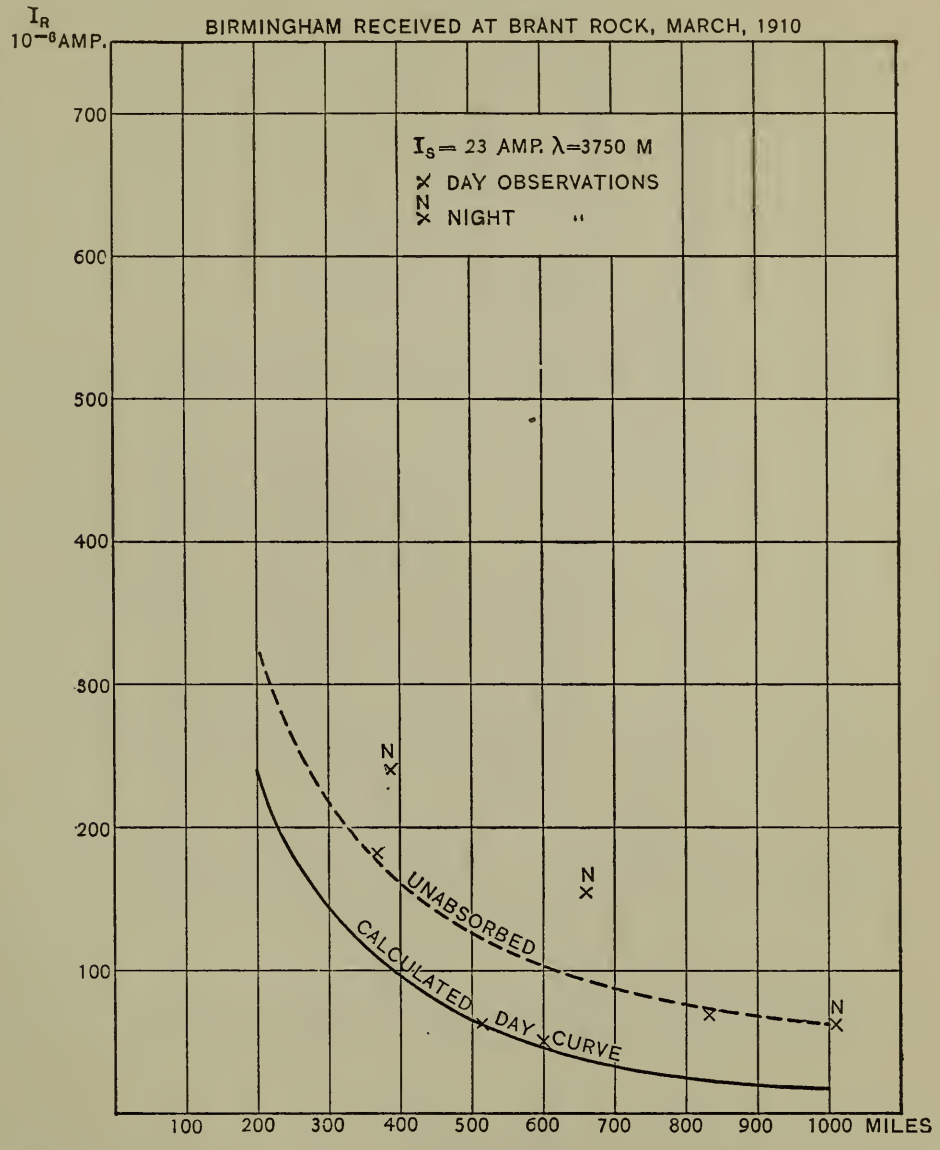

Fig. 21

the latest inductively coupled type, and perikon detectors were used which were standardized by comparison with electrolytic detectors, which experiments have shown to have a constant sensitiveness when properly adjusted. The ratio of current sensitiveness of the electrolytic to the perikon in both cases was approxi-

TABLE XVII

	Distance, Nautical Miles	Stringham Received on Bailey $\lambda=340$ m			Bailey Received on Stringham $\lambda=280$ m			I_R Average of Received Currents Corrected to Electrolytic and to $I_S=7.2$ amp. 10^{-6} amp.
		I_S amp.	Received Current 10^{-6} amp.		I_S amp.	Received Current 10^{-6} amp.		
			Observed	Corrected to $I_S=7.2$ amp.		Observed	Corrected to $I_S=7.2$ amp.	
Nov. 3, 1910	21.5	5.45	170	225	5.4	.....	.....	253
	33	6.00	132	159	5.1	87	123	158
	43	6.14	68	80	5.1	86	121	112
	55	6.00	58	70	5.1	76	107	99.0
Nov. 7,	65	6.27	55	63	7.5	75	72	75.5
	83	6.54	51	56	7.5	57	55	62.2
	100	6.00	39	47	7.2	45	45	51.6
Nov. 8,	122	6.55	23.9	26	7.0	32	33	33.0
	131	6.27	24.5	28	7.0	33	34	34.8
	156	6.82	Interference		7.0	18	18.6	20.9

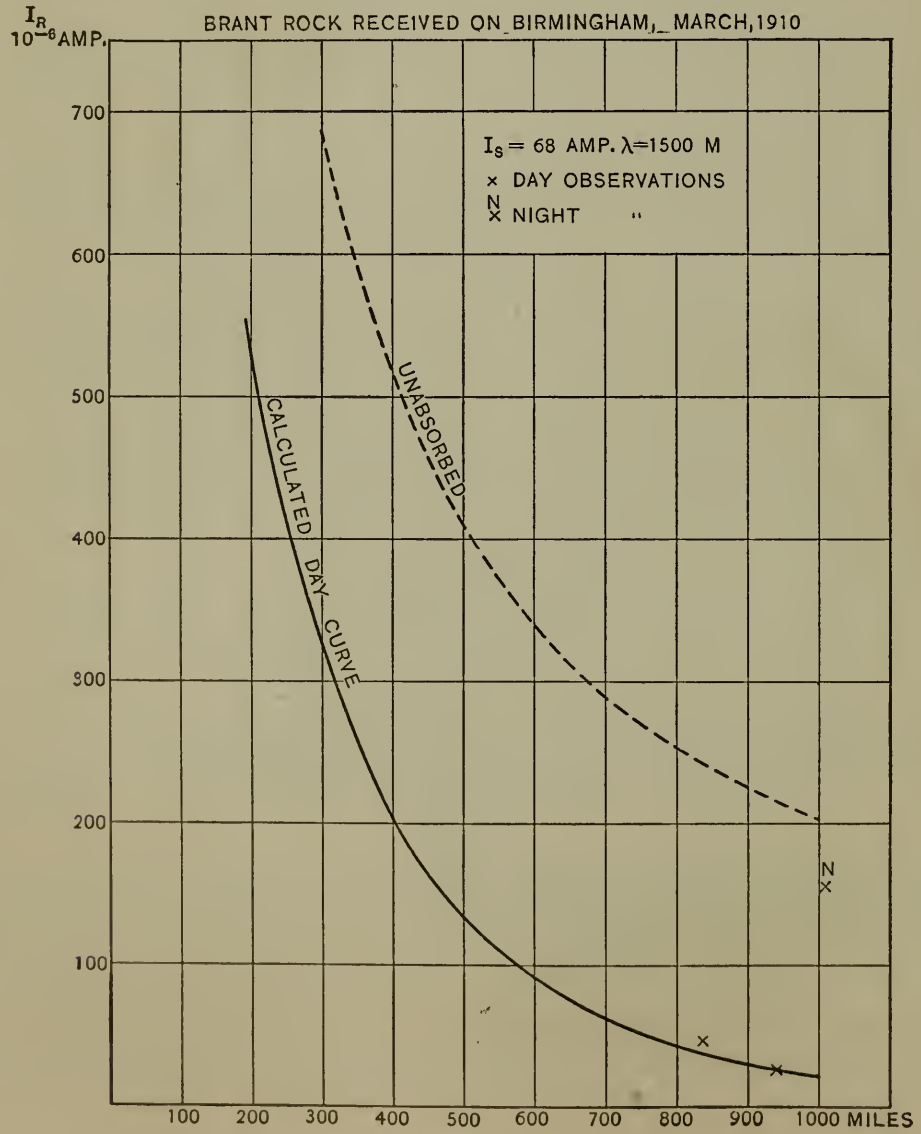

Fig. 22

mately 1.12. The telephones on both boats were of approximately the same sensitiveness and were of 2000 ohms resistance with an inductive resistance under working conditions of about 4000 ohms.

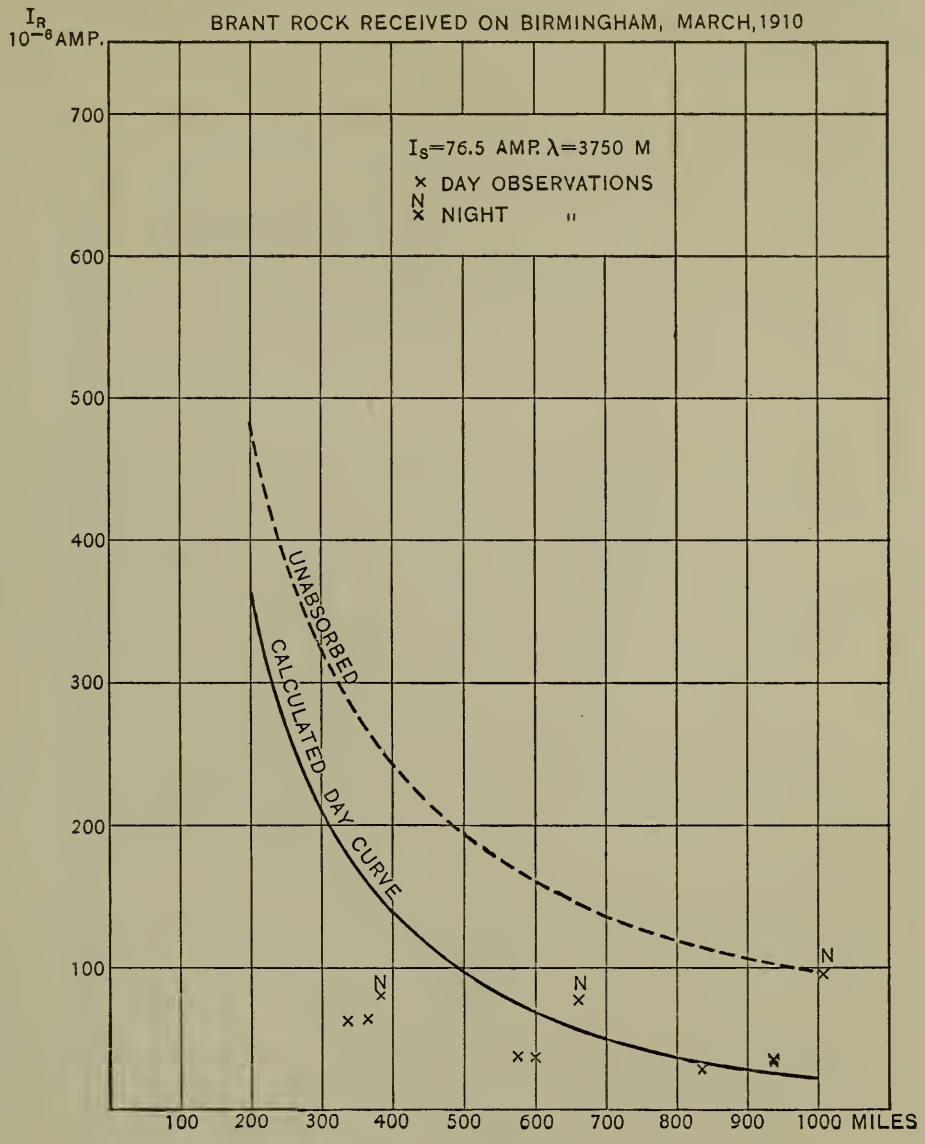

Fig. 23

The observations of these tests, shown in Table XVII, were taken with great care, the engines being stopped during the time of observation. Each one is the mean of a number of readings.

In the last column are given the received currents averaged for both boats corrected to a sending current of 7.2 amperes and to the readings of the electrolytic detector. In Fig. 28 is shown the

curve as calculated from Table XVI for antenna heights of 37.5 feet, a sending current of 7.2 amperes, and a wave length of 300 meters. The agreement is remarkable, considering the fact that the table from which the theoretical curve was calculated was based on data derived from ships with 130-foot masts working at

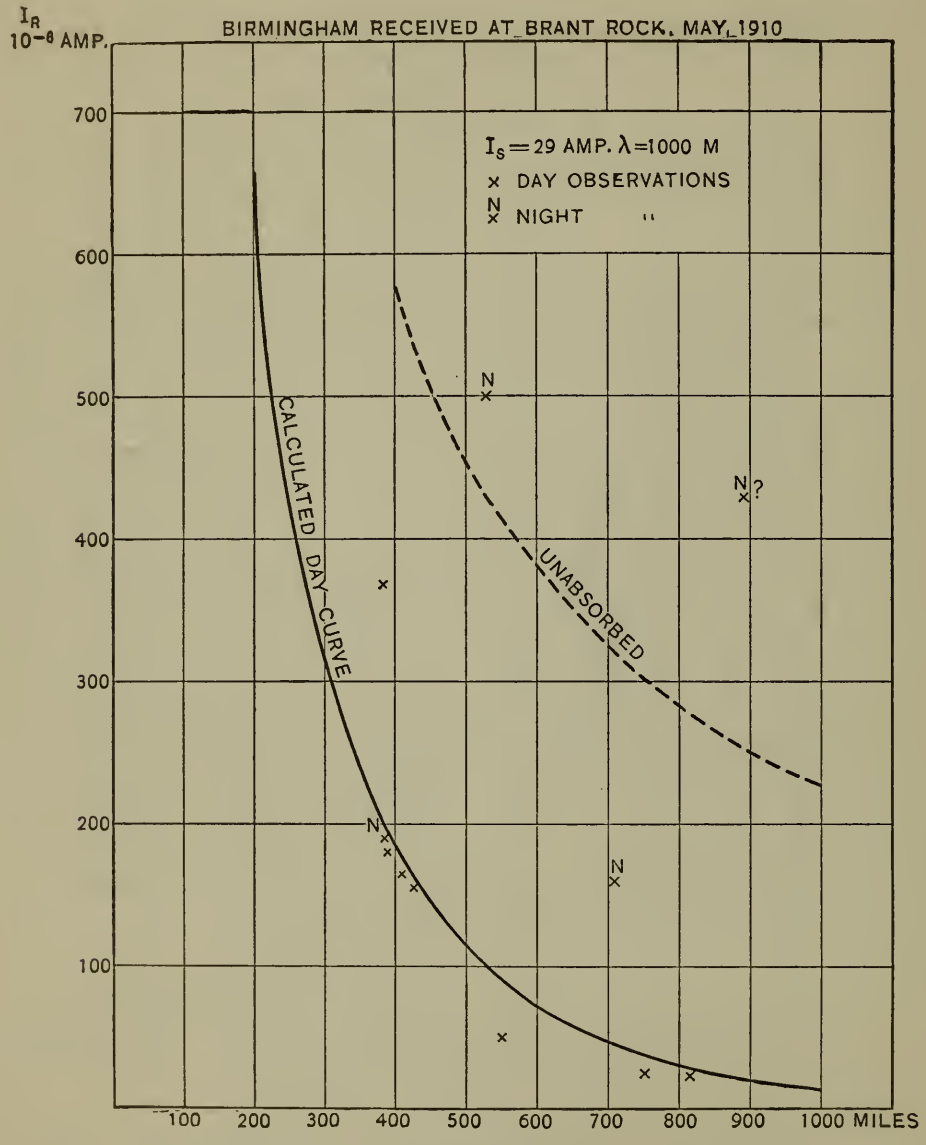

Fig. 24

a wave length of 1000 meters and employing a spark frequency of 1000 per second. These results show, as has often been observed in our laboratory, how little the ratio of sending currents and received signals depends on the spark frequency, the telephones apparently never showing the added sensitiveness for high frequencies exhibited in the case of sinusoidal alternating currents.

SUMMARY AND CONCLUSIONS

Quantitative measurements have been carried out in long distance wireless telegraphy up to 1000 miles for the purpose of determining the law of the variation of strength of signal with distance.

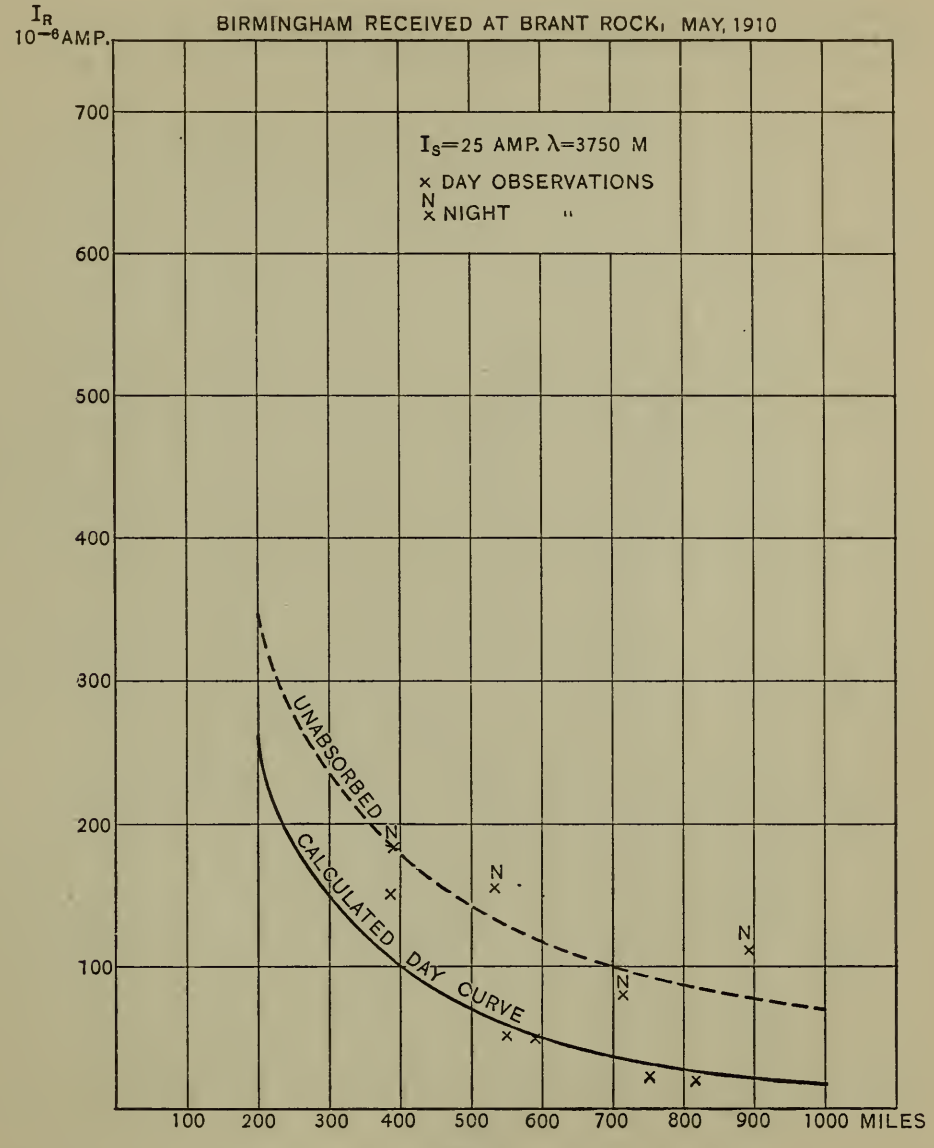

Fig. 25

Supplementary work was also done on the effect of height of antenna and wave length on sending and receiving.

The results are given briefly as follows:

(*a*) Over salt water the electrical waves decrease in intensity in proportion to the distance as found by Duddell and Taylor. In addition they are subject to an absorption which varies with the

wave length and which may be expressed mathematically by the term e^{-Ad}.

The complete expression for the received current is then

$$(2) \quad I_R = \frac{K}{d} e^{-Ad}$$

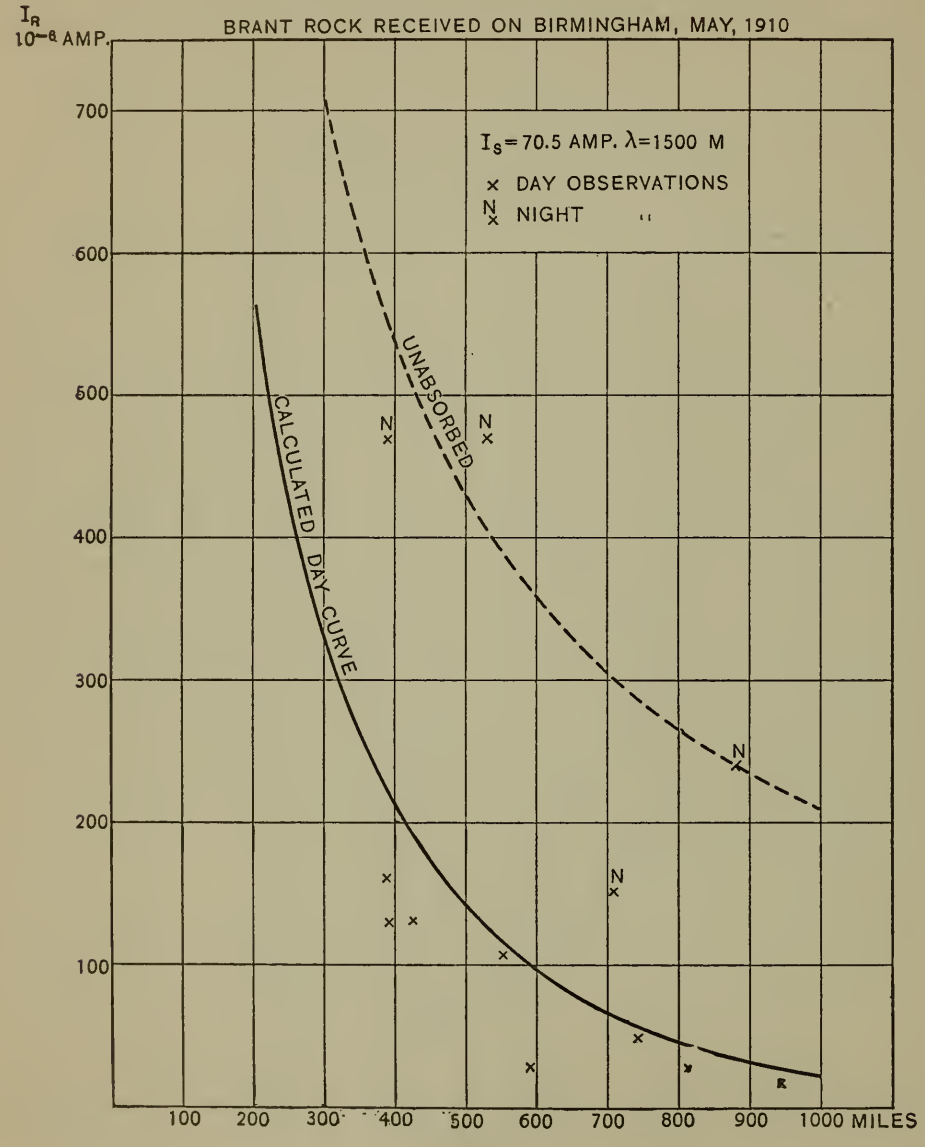

Fig. 26

This is true in general for day transmission. The absorption at night is entirely irregular varying from zero to the day value,[17] but is on an average much less during the winter than in summer.

[17] The great variations in night absorption make useless all attempts to judge the quality of wireless apparatus from night distances. For this purpose only observations on the average day range have any value.

Variations also appear to occur during the daytime, but these are probably in general small.

(*b*) The received antenna currents between two stations with salt water between are proportional to the product of the heights [18]

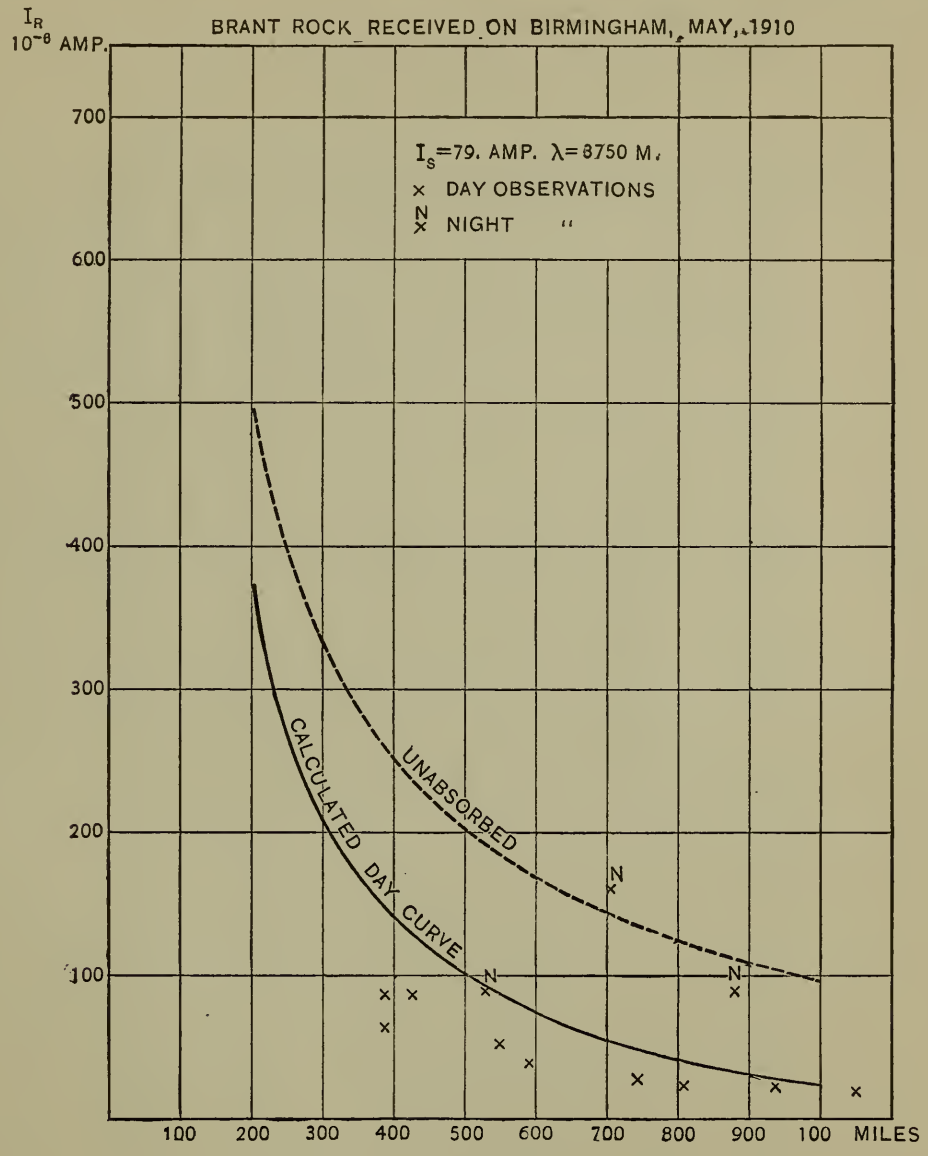

Fig. 27

of the sending and receiving antennas and inversely proportional to the wave length, provided the antenna resistances remain constant. These experiments were carried on with flat-top antenna

[18] The experiments indicate that for the greatest efficiency of a flat-top antenna the vertical lead wires should be bunched so as to reduce their capacity as much as possible and concentrate the capacity at the greatest height.

heights of from 30 to 80 feet and wave lengths from approximately 1500 to 4000 meters.

(*c*) Taking account of the influence of antenna height and wave length equation (2) may be extended and a general day transmission formula written as follows

$$(3) \quad I_R = 4.25 \frac{I_s \, h_1 \, h_2}{\lambda d} e^{-\frac{0.0015\, d}{\sqrt{\lambda}}}$$

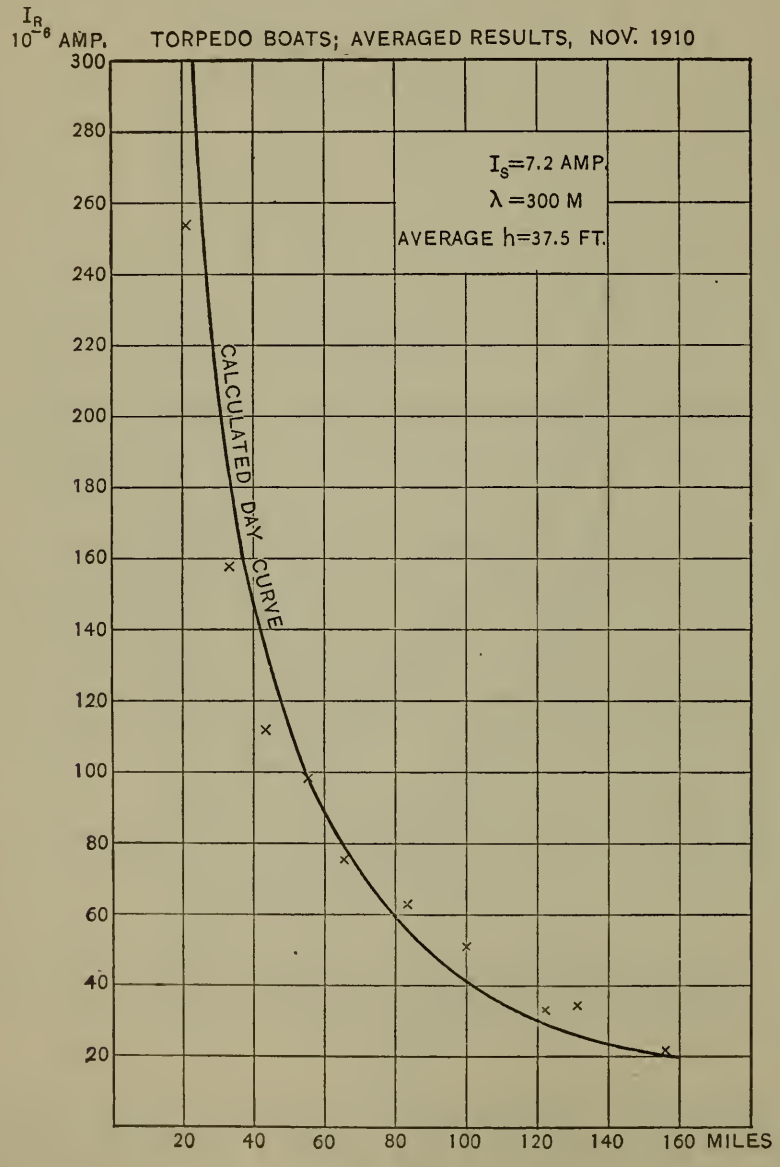

Fig. 28

where the currents are given in amperes and all lengths in kilometers.[19] This formula has been tested for sending currents from

[19] From this it would appear that it is advisable to rate stations according to the magnitude of the antenna current, or perhaps better, according to the product of the current into the height.

7 to 30 amperes antenna heights 37 to 130 feet, wave lengths from 300 to 3750 meters, and distances up to 1000 nautical miles.

In regard to the value of the day absorption it is only possible to say that the above expression is satisfied within the limits of error of the observations. It is quite possible that when observations are made at distances of 2000 to 3000 miles, the value of the absorption coefficient will have to be corrected by 10 or even 20 per cent, as this amount of error could exist without discovery at the distances covered in these experiments. It is also possible that the square root law relating the absorption with the wave length is only an approximation.

U. S. Naval Wireless Telegraphic Laboratory,
Washington, February 1, 1911.